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GUIDELINE FOR PLANNING CABLE SYSTEM LOGGING ROADS ON STEEP TERRAIN

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EXPLANATION OF TERMS

Jammer logging:

Basically this is a scaled down version of the high lead logging done in the coastal Douglas-fir region. In both cases the logs are dragged along the ground to the yarder (or tower) by the mainline, and the tongs (or chokers) after being unhooked are dragged back to the down timber by the haulback line. On the West Coast true high lead logging is practiced using large towers, heavy cable, and high horsepower yarders because heavier logs and longer yarding spans are common. Here in the Inland Region the different conditions (smaller timber and cheaper road construction) have resulted in the development of scaled down high lead yarders called jammers. More recently road construction standards and costs have risen and we find increasing need for longer span jammers that permit operability with fewer roads. Some of these long span jammers rival the true high lead span capability of 1000 feet. However, their towers have not increased proportionately in height and they are still referred to as jammers or ground lead systems.

Clamping carriage:

More correctly called fixed carriage. These are used with a skyline operation and must run elevated above the ground, supported by the taunt skyline. The carriage moves along skyline by sheaves (or metal wheels), and is controlled by other lines that are attached to the carriage. A skyline carriage, especially when operating in a partial cut, must be capable of maintaining a fixed position on the skyline. Whether this is done by mechanical clamping brakes or if it is held in position by a haulback line does not really affect its operating suitability. Generally, an uphill live skyline operation will require a true clamping carriage, while a running skyline operation provides for a stationary carriage by holding it with the haulback line.

Skyline logging:

System of logging where the logs are suspended from a carriage that travels above the ground and is supported by a taunt cable. Generally at least one end of the log is lifted above ground during yarding.

I - ROAD WIDTHS

A. INTRODUCTION

Determining the correct procedure for timber harvest in steep terrain presents a real problem to Forest Service land managers. In many cases natural slopes are already standing at their maximum safe degree of steepness. To plan road construction crossing these areas is to invite the occurrence of mass soil failures.

Basically two questions should be resolved prior to planning the road systems required for timber harvest in these areas:

1. Should any road be constructed in this terrain?

2. If road construction is permissible, what are the maximum safe design dimensions (width and cut slopes) of the road?

The correct resolution of those questions to a large extent determines the type of logging system required to harvest the timber.

Assuming the most economical yarding system physically capable of operating from the designated road widths is selected, the logging systems required would be categorized as follows:

Where roads cannot be permitted, yarding systems would be limited to helicopters or long-span skylines.

If roads must be limited to 12 feet in width, only small jammer-sized yarders should be stipulated.

If road prisms 15 foot plus in width are permissible, larger ground-lead or skyline yarders can be utilized.

This choice of yarding hardware may necessitate some trade-offs in environmental impacts. For example, use of a skyline yarder should result in fewer mid-slope roads than what would be required for small jammer-type yarders. On a long sustained slope the maximum road spacing for skyline yarding may approach 700 feet, while road spacing for a jammer may be limited to 500 feet. Furthermore, skyline yarding with a fixed carriage provides a better method for minimizing damage to the residual stand in a partial cut.

However, protection of the soil, which is the basic resource, should take precedence over all other considerations. On this basis, it is better to have constructed five narrow and stable mid-slope roads across a given hillside, than to have four wider roads where mass failures are occurring.

In partial cut situations, the choice of jammer-sized equipment over the larger skyline yarders does not necessarily have to result in greater damage to the residual stand. Double drum jammers with guyed towers are capable, when equipped with a clamping carriage, of functioning as skylines, though this has rarely been practiced. Furthermore, other scaled down yarders having skyline capabilities will become more available in time.

However, even if small yarders had only ground lead capability, their use in partial cuts may still be preferable to larger yarders where critical soil conditions exist. In short, its better to have a few more skinned-up trees on stable ground, than a damage free stand on terrain where massive slumps have been triggered.

Logging with roads even narrower than 12-foot jammer sized roads is a further possibility. In Japan they practice tractor logging with minimal soil impact on 70% sideslopes. Using small rubber-tired skidders with larger winches, they construct 8-10 foot wide level roads spaced at 200-250 feet.

However, the purpose of this guideline is not to promote, or ban, any particular yarding system; but aid only in determining what kind, if any, road should be built crossing questionable areas.

The approach presented in this section is a take-off on the method presented by Rod Prellwitz in the slope stability workshop, which was held at Canoe Gulch in May, 1974. While this workshop was attended by many District and S.O. engineering personnel, attendance is not a necessary pre-requisite for understanding the technique presented here.

Analytical Graphs are provided for determining the maximum safe road widths that can be constructed on a given slope, with a given road cut slope for various soil types where the ground water table is not encountered. Where a high water table exists, Prellwitz's method can be used in determining the safe limits of road construction; however, that complication was deleted from this section as so many combinations of water table depths can occur that this graph approach would have to be broadened drastically.

This presentation will certainly not alleviate the need for geology or soil specialists. The possible range of basic parameters, even within a given soil type, are so broad that their expertise will be taxed. At best, this approach will provide the planner with a better understanding of what range of soil parameters can be expected on Kootenai soil types, and how these values limit the safety of road construction.

B. DEFINITION OF TERMS

Three basic soil properties which adequately determine a given soil's stability are:

1. Internal angle of friction (called ϕ angle)

The steepest angle which a given soil can safely stand if the soil has no cohesion. Dry loose sand, if poured out of a container, will build up in a cone-shaped mound, and the slope angle of its sides approximate the sand's angle of friction. Generally fine textured soils have a lower angle of friction than course grained, rocky, angular soils.

2. Cohesion

The internal strength given to a soil by elements other than its own structural properties that tends to hold its particles together. Soil moisture and consolidating pressures are examples of these elements. For example sandstone may be looked upon as an over consolidated sand that exhibits much higher strength (cohesion) than the original parent material.

3. Soil Density

The unit weight of the natural soil. The heavier a soil with a given angle of friction and cohesion strength is, the more likely stability failure is apt to occur, as the soil moves because of the gravitational force acting on its mass.

C. PROPERTIES OF KOOTENAI SOILS 1/

The Planning Branch has mapped much of the Forest into land types. These land types consider composition of the overburden deposit, depth to bedrock, slope, aspect, and drainage characteristics. These land types are combined with vegetative cover to describe an Ecological Land Unit. The description of the land types includes a possible range of what the average material may be. There will be a large variety of other materials in the deposit, that will not specifically follow the average description. However, it is possible to describe the average overburden deposits in engineering terms and discuss a range of strength parameters for that soil.

Basically, the land types are described in five major categories as follows:

1. 100 - stream deposits, labeled silts, and glacial-fluvial
2. 200 - oversteepened areas normally at the head of a drainage
3. 300 - glacial deposits associated with the continental ice sheets
4. 400 - deposits related to alpine glaciation and soils that have been modified by intense frost action or subsurface frost churning
5. 500 - soils forming from residual parent material

These five groups of land types are described below in engineering terms. It cannot be overemphasized that these properties are an educated guess, at best, and there will always be materials encountered that will not fall in these ranges. The Unified Classification Symbol and engineering description are derived from the land type description prepared by the Planning Branch. Values for inplace

1/ This section is written by Bob Kaufman, Materials Engineer

density and angle of internal friction have been selected from past experience, literature review, and consideration of the geologic history of the deposit. Basically , all of the surface deposits on the Kootenai are non-plastic. They will not exhibit true cohesive values. Values for cohesion were selected to illustrate a possible range of apparent strength, dependent on moisture content. Finally, all of the values in the following table are considered for the dry or moist condition and must not be used for saturated soils.

LAND TYPE NO.	GENERAL DESCRIPTION	UNIFIED CLASSIFICATION SYMBOL	ENGINEERING DESCRIPTION	IN PLACE MOIST DENSITY (PCF)	INTERNAL ANGLE OF FRICTION (DEGREES)	APPARENT COHESION (PSF)
	Flood Plain	GP to SP	Sandy Gravel to Gravelly sand (rounded) w/ cobbles & boulders	90 - 125 (107.5 m.r.*)	25 - 35 (30^{0} m.r.)	0
	Lakebed	ML to SM	Sandy Silt to Silty Sand w/ occasional gravel, cobbles & boulders	75 - 120 (97.5 m.r.)	15 - 30 (22.5 m.r.)	0 - 400 (200 m.r.)
100	Glacial-Fluvial	SP to GP-GM	Gravelly Sand to Sandy Gravel (sub-rounded) w/ silt & some cobbles & bldrs.	80 - 130 (105 m.r.)	25 - 38 (31.5 m.r.)	0 - 50 (25 m.r.)
	Lacustrine	ML to CL	Sandy Silt to Sandy Clay (low plasticity)	75 - 110 (92.5 m.r.)	10 - 25 (17.5 m.r)	50 - 500 (275 m.r.)
200	Glacial Till & Residual	SM to GM	Silty Sand to Silty, Sandy Gravel (subangular) w/ occasional cobbles & bldrs.	90 - 135 (112.5 m.r.)	28 - 40 (34 m.r.)	0 - 200 (100 m.r.)
300	Glacial Till & Fluvial	SM to GM	Silty Sand to Silty, Sandy Gravel (subangular to sub-rounded) w / occasional cobbles & bldrs.	90 - 140 (115 m.r.)	28 - 40 (34 m.r.)	0 - 200 (100 m.r.)

* denotes mid range

LAND TYPE NO.	GENERAL DESCRIPTION	UNIFIED CLASSIFICATION SYMBOL	ENGINEERING DESCRIPTION	IN PLACE MOIST DENSITY (PCF)	INTERNAL ANGLE OF FRICTION (DEGREES)	APPARENT COHESION (PSF)
	Calcaerous Glacial Till & Fluvial (323,324,325)	GP to GM	Sandy Gravel to Silty, Sandy Gravel (sub-rounded) w/ occasional cobbles & boulders.	90 - 140 (115 m.r.)	28 - 40 (34 m.r.)	0 - 300 (150 m.r.)
	Deep Sand (371)	SP to GP	Gravelly Sand to Sandy Gravel (sub-rounded)	80 - 130 (105 m.r.)	25 - 38 (31.5 m.r.)	0
400	Alpine Tills & Frost Heaved	SM, SP-SM GP, GP-GM & GM	Silty sand; sand w/silt & Gravel; Sandy gravel; Sandy gravel w/silt; Silty, Sandy, Gravel (angular to subangular w/occasional cobbles & bldrs.	90 - 135 (112.5 m.r.)	30 - 45 (37.5 m.r.)	0 - 100 (50 m.r.)
500	Residual Soils	GP, GP-GM, GM	Sandy Gravel; Sandy Gravel w/silt; Sandy, Silty Gravel (angular) w/ occasional cobbles & bldrs.	110 - 145 (127.5 m.r.)	35 - 50 (42.5 m.r.)	0 - 100 (50 m.r.)

These values for density, internal angle of friction, and cohesion are based on a short literature review and personal judgment.

D. DERIVATION & EXPLANATION OF MAXIMUM ROAD WIDTH GRAPHS

Twelve maximum road width graphs are presented starting on page 15. They were constructed from repeated solutions of critical cut heights for various conditions. The mathematical foundation of these graphs is based on a stability number solution for critical cut height. 1/

The basic equation expressing this is:

$$Hc = \frac{NC}{F}$$

where

Hc = Critical cut height in feet -- that is the maximum cut height that can be expected to remain stable or, if a higher cut is constructed, mass failure is probable.

N = Stability Number determined from Figure 4 (see page 14) that varies with the cut slope of the road, the internal angle of friction of the soil (ϕ), the slope of the ground (α)

C = Soil Cohesion in pounds per square feet

F = Soil Density in pounds per cubic foot

When a correct stability number (N) is selected, the maximum safe cut height (Hc) can be determined if the soil density (F) and the cohesion (C) are also known.

And with the maximum cut height known, the corresponding road width can easily be determined graphically or mathematically as the slope of the ground and the slope of the cut are known.

1/ This approach was presented by Rod Prellwitz in the Slope Stability Workshop held at Canoe Gulch in May, 1974.

The mathematical solution for critical width is:

$$Wc = Hc \left(\frac{1}{\tan \alpha} - \frac{1}{\tan \beta}\right)$$

where

Wc = Critical or maximum road width (feet)

Hc = Critical Height

α = Side slope in degrees

β = Excavated slope (degrees)

E. USE OF ROAD WIDTH GRAPHS

A practical example of the procedure to follow in using these Road Width charts provided here:

A transportation planner is trying to determine what type (if any) of road can safely be constructed that will cross sideslopes of up to 70%. The multiple-use plan indicates the roads in question will cross ELU-48; which is characterized as oversteepened with land types 201, 202, 251, 401, 402 and 403.

Referring to the table in section I-C. indicates the following properties for these land types:

	Density	Internal ϕ Angle	Cohesion
200 series	90 - 135 pcf	28 - 40^{o}	0 - 200 psf
	112 pcf mid range	34^{o} mid range	100 psf mid range
400 series	90 - 135 pcf	30 - 45^{o}	0 - 100 psf
	112 pcf mid range	37.5^{o} mid range	50 psf mid range

The planner wishes to use a 3/4:1 cut slope, if possible, rather than a 1:1 cut. The advantage of the steeper slope is that it reduces the land taken out of production by roads, somewhat the visual impact of the road, and the cost of road construction. The disadvantage however is that mass failure is more apt to occur with the steeper cut slope.

This example will show the analysis only for soils in the 400 land types. However, if the roads go through both the 200 & 400 land types both should be checked. A more exact delineation of land types than can be extracted from the ELU maps is available on large map overlays in Supervisor's office. Each land type is shown individually.

Going to Figure 5 on page 19 to determine the maximum road width for land types in the 400 series, with a 3/4:1 cut slope ratio and the slope at 70%, information can be extracted by the following procedure:

1. Assume the density of the soil to be 112 pcf
2. Check what the maximum (or critical) road width is at the mid range ϕ angle of 38° and the mid range C value of 50 psf by:

    a. Laying a straight edge from 112 pcf soil density on the left margin to 50 psf cohesion on the right margin.
    b. Note the straight edge intersects the curve for $\phi = 38^{\circ}$ and C = 50 at a point.
    c. From this point, drop straight down to the horizontal axis and pick-off the maximum road width which in this case is 11.3 feet.

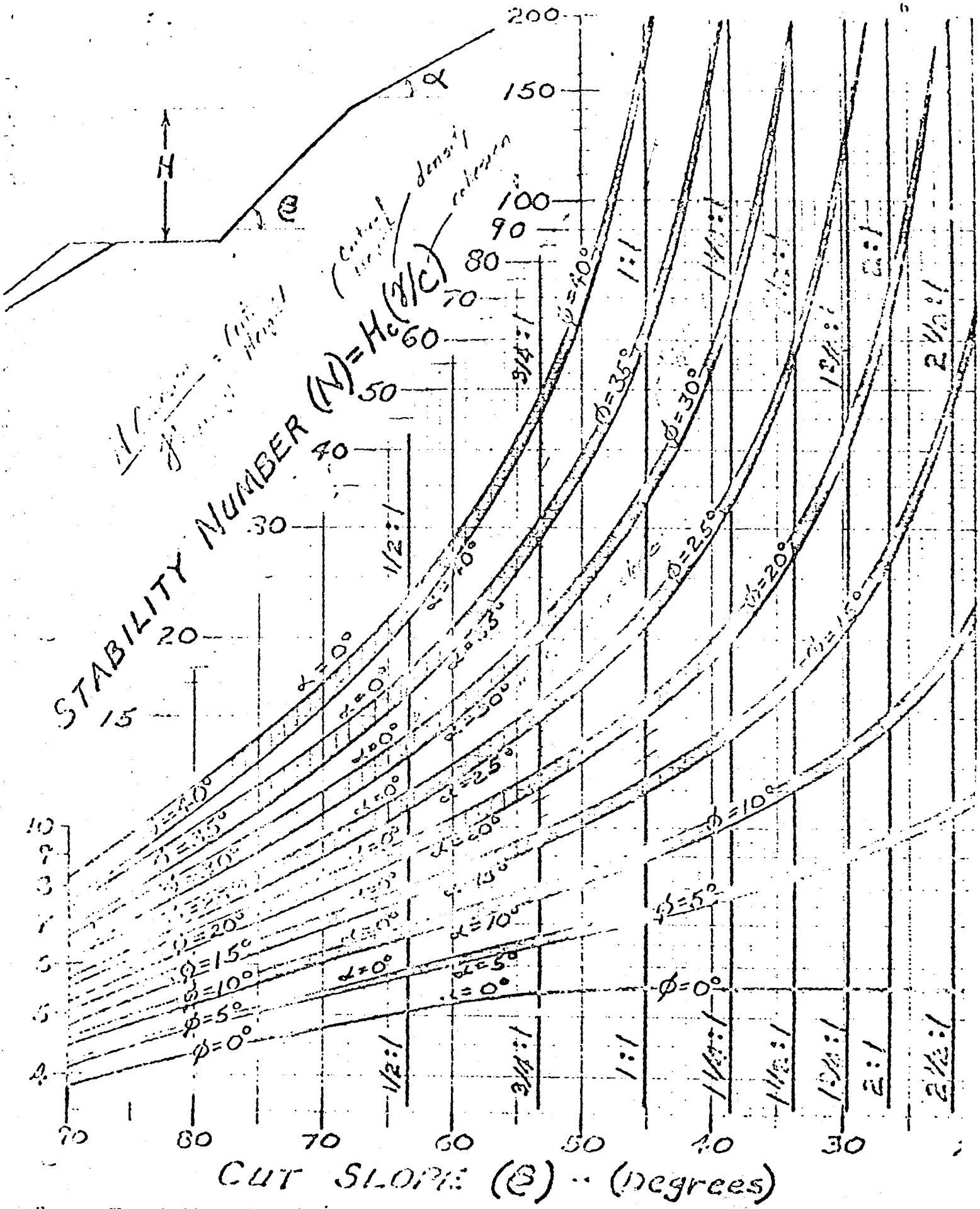
Going to the minimum ϕ value of 30° and the minimum C value of 0 psf, one can note the following. If the soil is actually cohesionless, the maximum slope at which it can stand is governed by its ϕ angle. This could not be 30° because it is now standing at 70% (or 35°) without exhibiting mass failure tendencies.

Considering the maximum ϕ value of 45% and the maximum C value of 100 psf is not very meaningful in most cases. If the planner is truly optimistic enough to assume these strength properties prevail, he can likewise assume that he can build a 40-foot wide road almost anyplace.

Assume the planner estimates the mid range values for C and ϕ, which indicated a corresponding maximum road width of 11.3 feet, provide a realistic value. As this width is too restrictive for any kind of road, he decides to analyze whether or not he can improve the road construction feasibility by using a 1:1 cut slope.

Going to Figure 6 and using the same technique, he determines the maximum road width to be 19.8 feet. So he learns that the flatter cut slope provides a less critical failure arc and a wider road can safely be constructed with a 1:1 slope.

On this basis he may decide to go ahead with the road, if the other considerations such as cost and esthetics permit it.



From: Chen & Giger (1971)

FIGURE NO. 4 - STABILITY NUMBER CHART

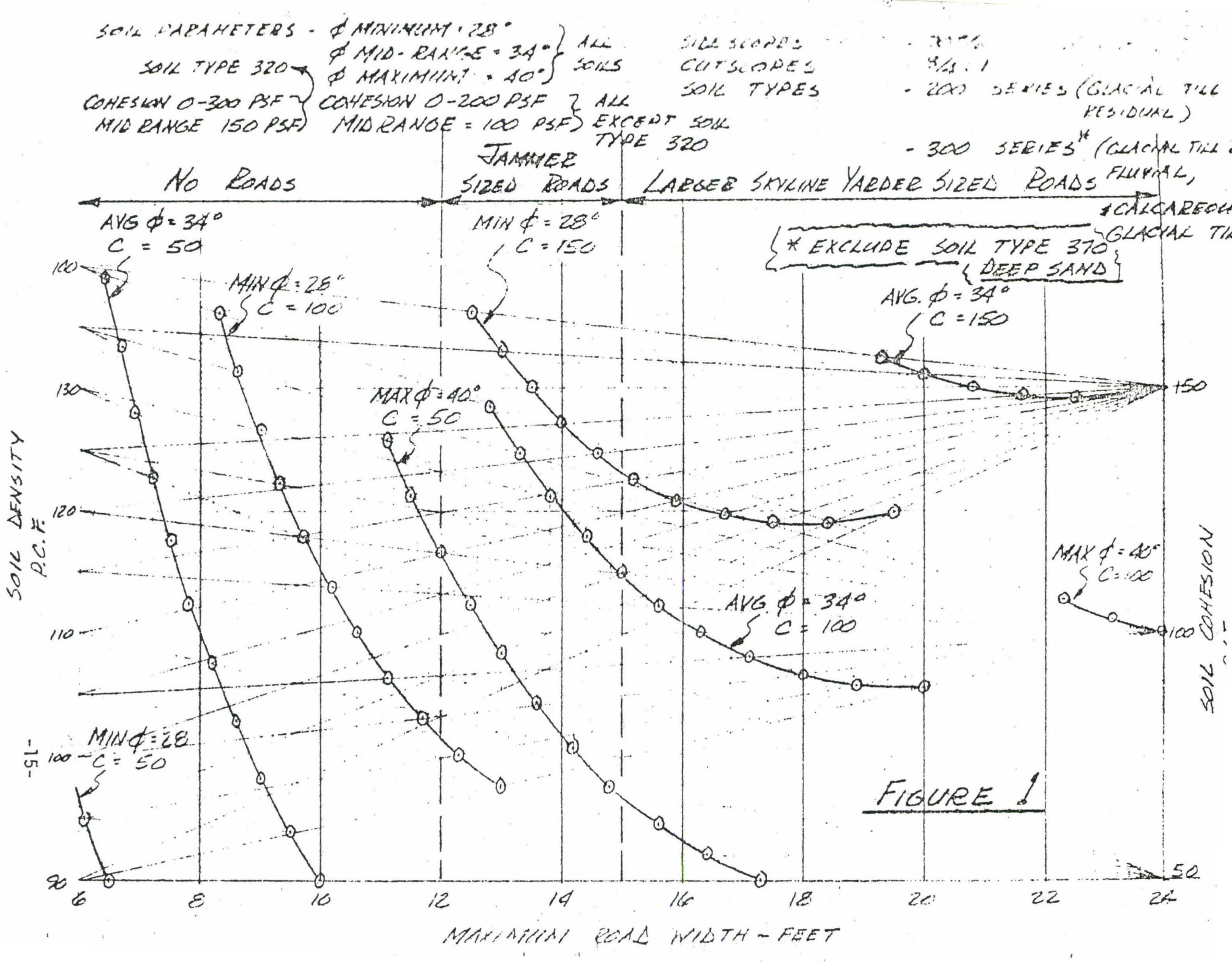

SOIL PARAMETERS - φ MINIMUM = 28°
φ MID-RANGE = 34°
φ MAXIMUM = 40°
ALL SOILS
SOIL TYPE 320
COHESION 0-300 PSF
MID RANGE 150 PSF
COHESION 0-200 PSF
MID RANGE = 100 PSF
ALL EXCEPT SOIL TYPE 320
SOIL SLOPES - 3/4 : 1
CUT SLOPES - 3/4 : 1
SOIL TYPES - 200 SERIES (GLACIAL TILL RESIDUAL)
- 300 SERIES* (GLACIAL TILL FLUVIAL,
*CALCAREOU
GLACIAL TI
NO ROADS
JAMMER SIZED ROADS
LARGER SKYLINE YARDER SIZED ROADS
AVG φ = 34°
C = 50
MIN φ = 25°
C = 100
MIN φ = 28°
C = 150
* EXCLUDE SOIL TYPE 370
DEEP SAND
AVG. φ = 34°
C = 150
MAX φ = 40°
C = 50
AVG. φ = 34°
C = 100
MAX φ = 40°
C = 100
MIN φ = 28
C = 50
SOIL DENSITY P.C.F.
SOIL COHESION
100
130
120
110
90
150
100
50
6
8
10
12
14
16
18
20
22
24
MAXIMUM ROAD WIDTH - FEET

FIGURE 1

SIDESLOPES - [illegible]
CUT SLOPES - 1:1
SOIL TYPES - 100 SERIES (GLACIAL TILL & RESIDUAL)
- 300 SERIES

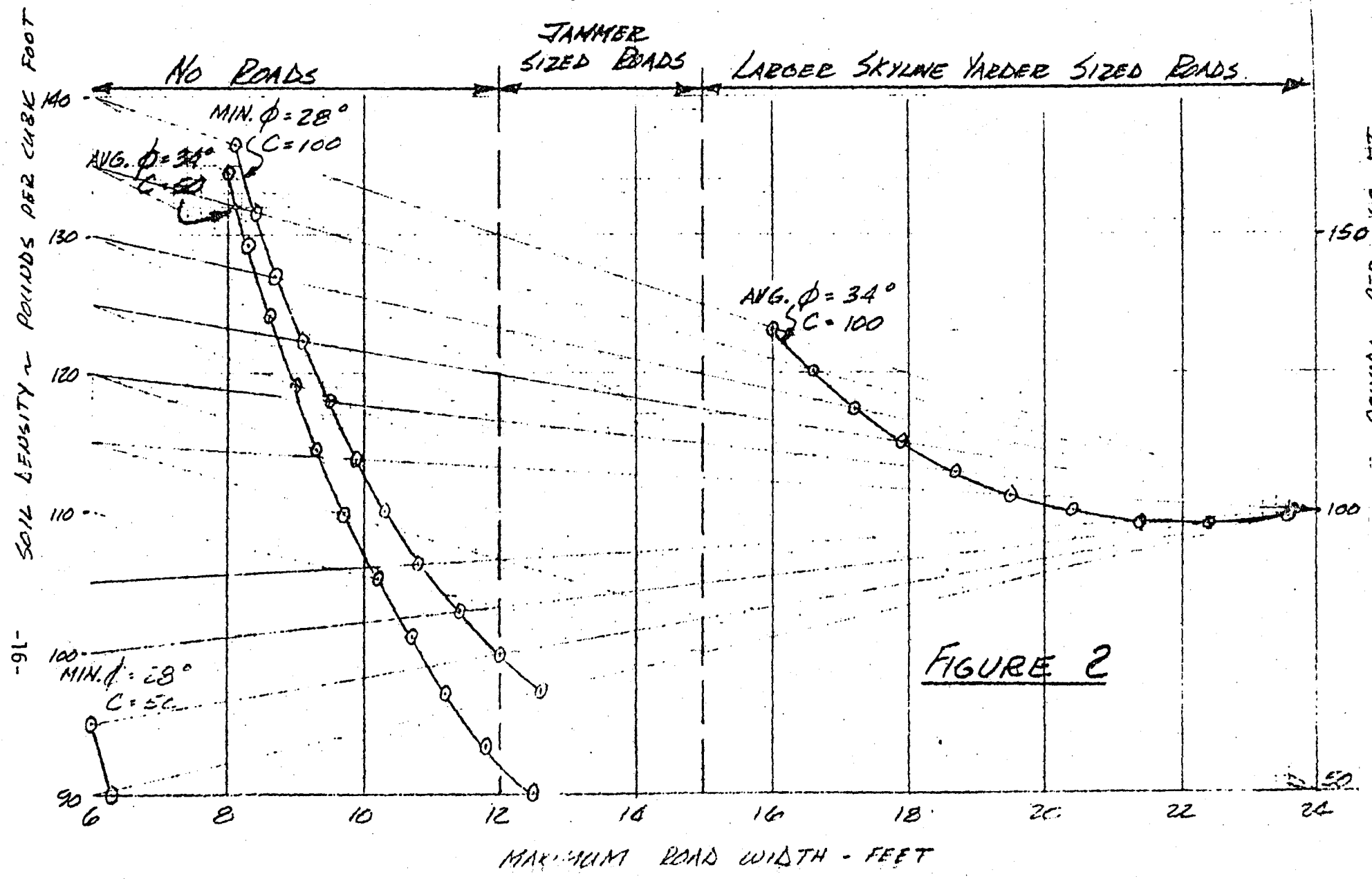


FIGURE 2

SIDESLOPES - 60%
CUT SLOPES - 3/4 "
SOIL TYPES - 200 SERIES (GLACIAL TILL & LESSIVAL)
- 300 SERIES

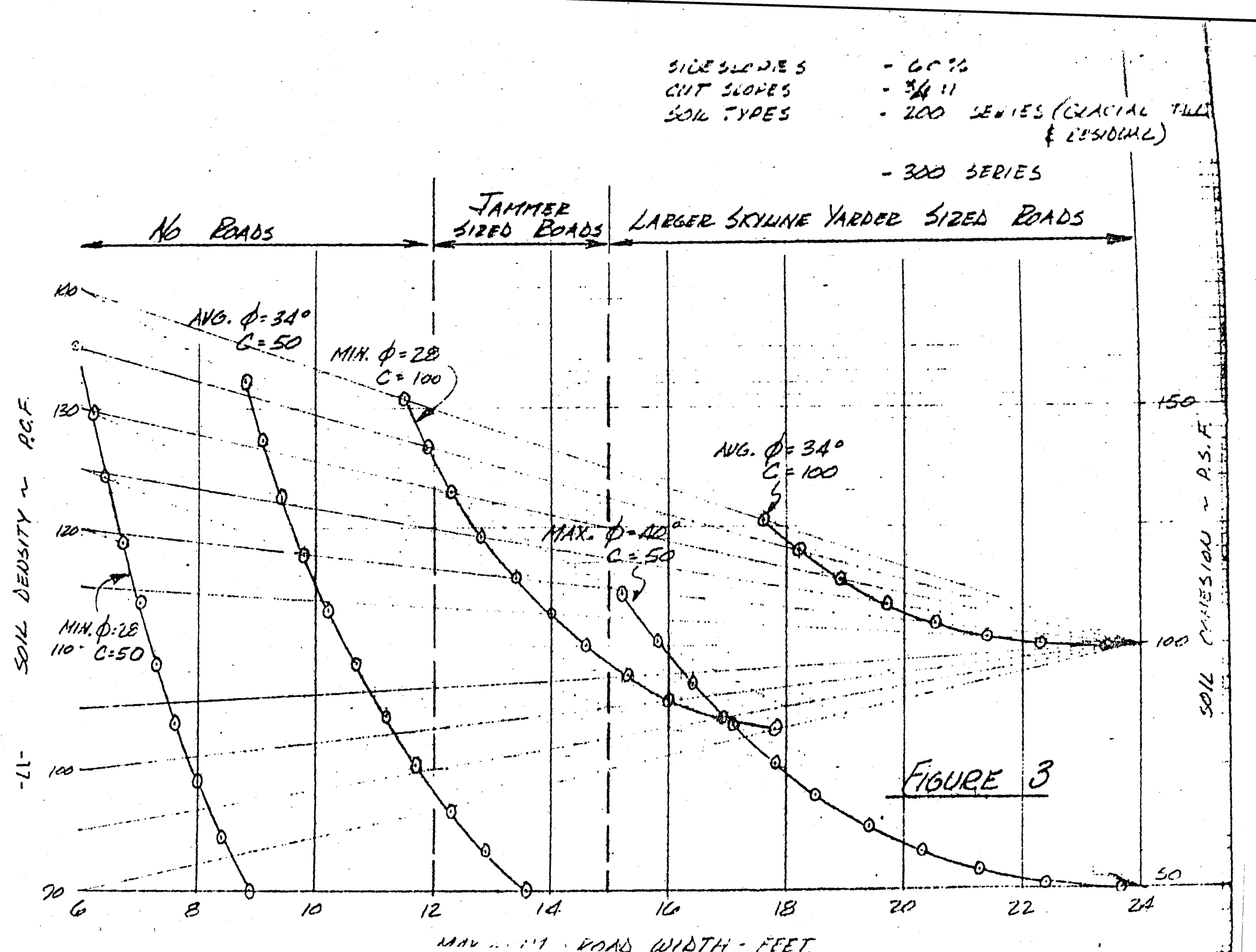


FIGURE 3

SIDESLOPES - 60%
CUT SLOPES - 1:1
SOIL TYPES - 200 SERIES (GLACIAL TILL & RESIDUAL)
- 300 SERIES 200
GLACIAL TILL & FLUVIAL
CALCAREOUS GLACIAL TILL
(DO NOT INCLUDE 370-DEEP SAND)

SOIL PARAMETERS-ϕ MINIMUM = 28° } ALL SOILS
ϕ MID-RANGE = 34°
ϕ MAXIMUM = 40°

COHESION 0-200 PSF
MID RANGE 100 PSF
COHESION FOR SOIL TYPE 150
320 AT 0-300 PSF
MIDRANGE 150 PSF

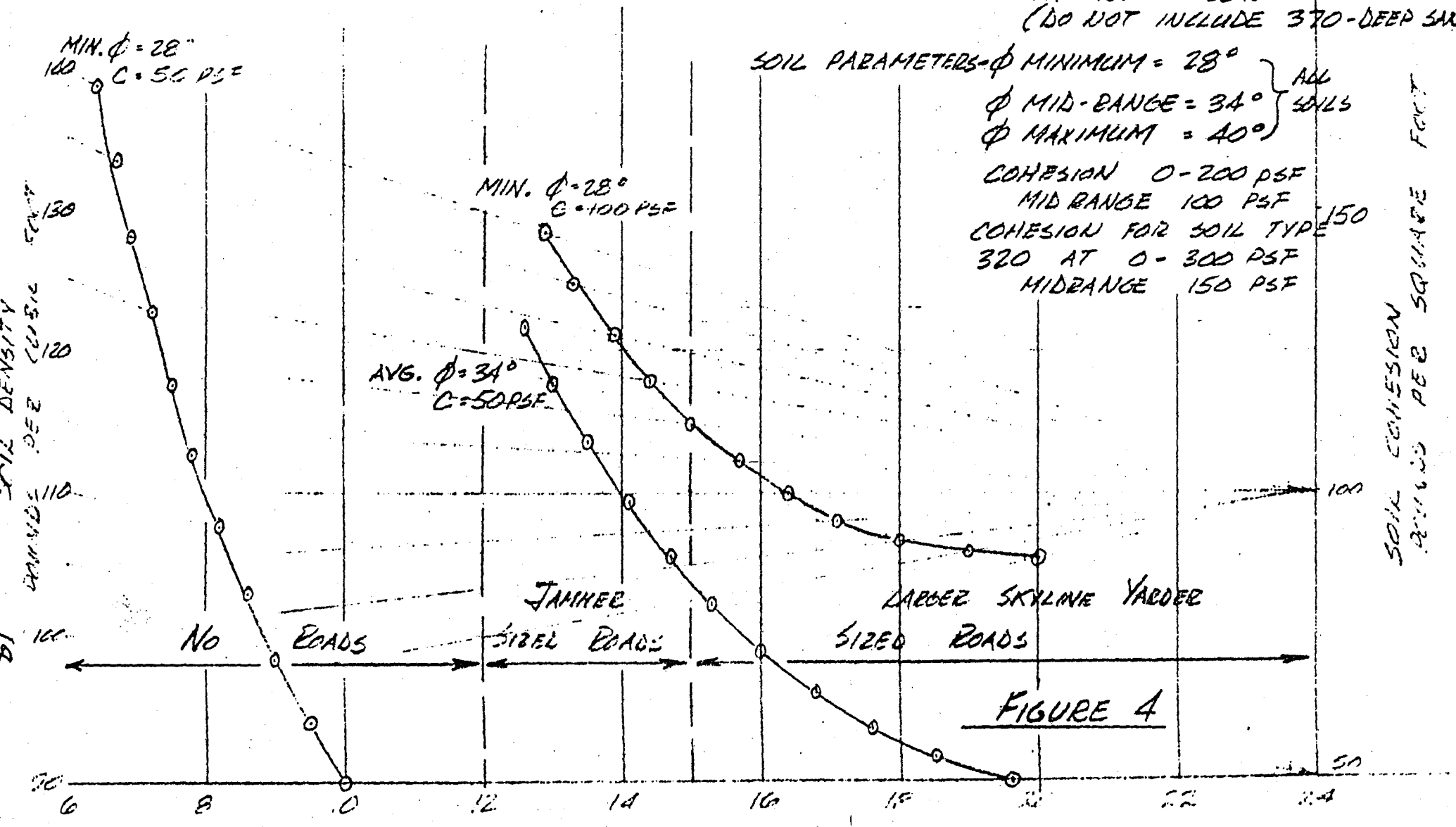


FIGURE 4

SIDESLOPES - 30%
GRADES - 3% UP
SOIL TYPES - 400 SERIES (ALLUVIAL TILL)
SOIL PARAMETERS - ϕ MINIMUM = 30°
ϕ - MID RANGE = 38°
ϕ - MAXIMUM = 45°
COHESION 0 - 100 PSF
MIDRANGE @ 50 PSF

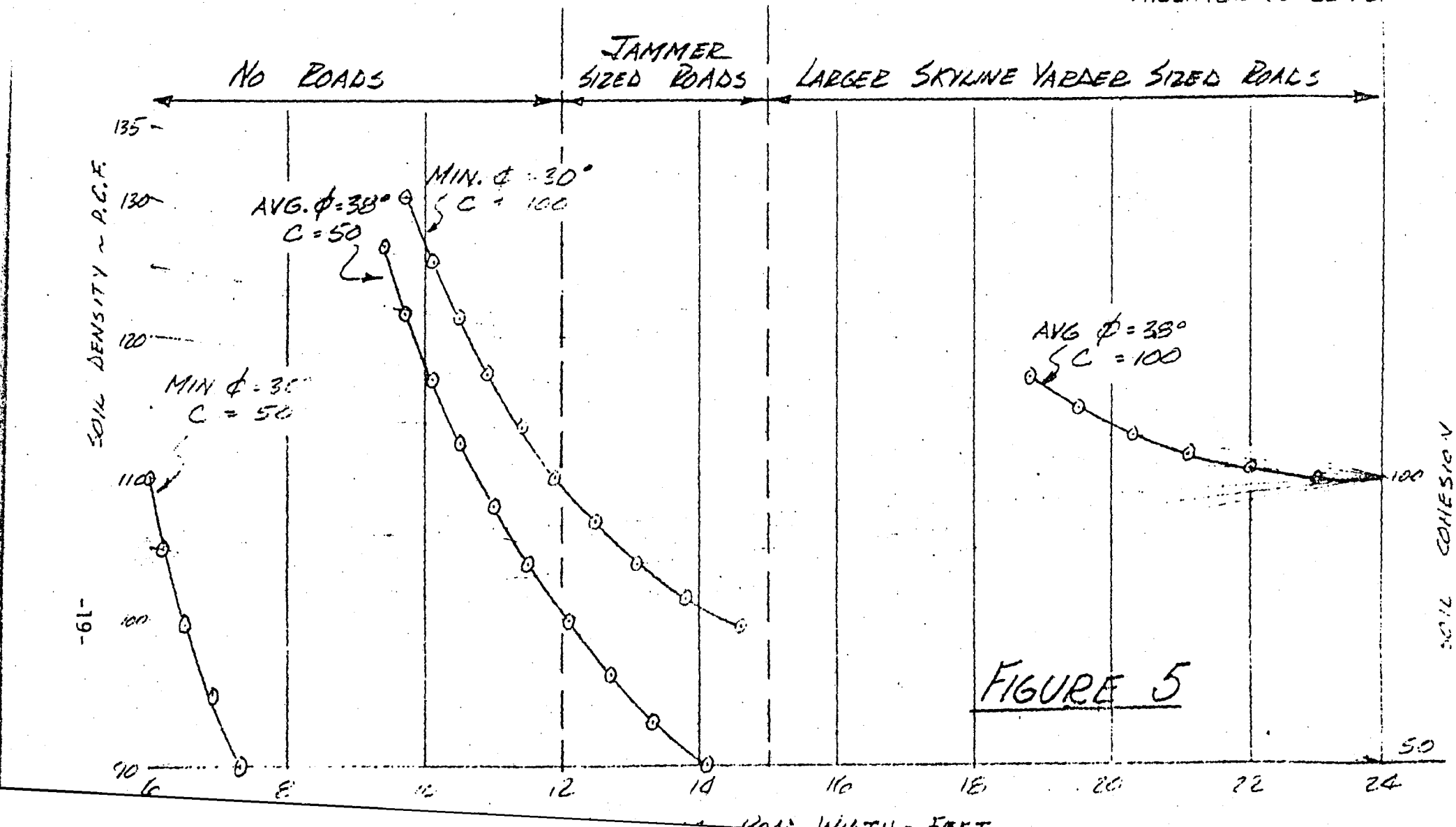


FIGURE 5

SIDESLOPE - 70%
CUTSLOPE - 1:1
SOIL TYPE - 400 SERIES (ALPINE TIL

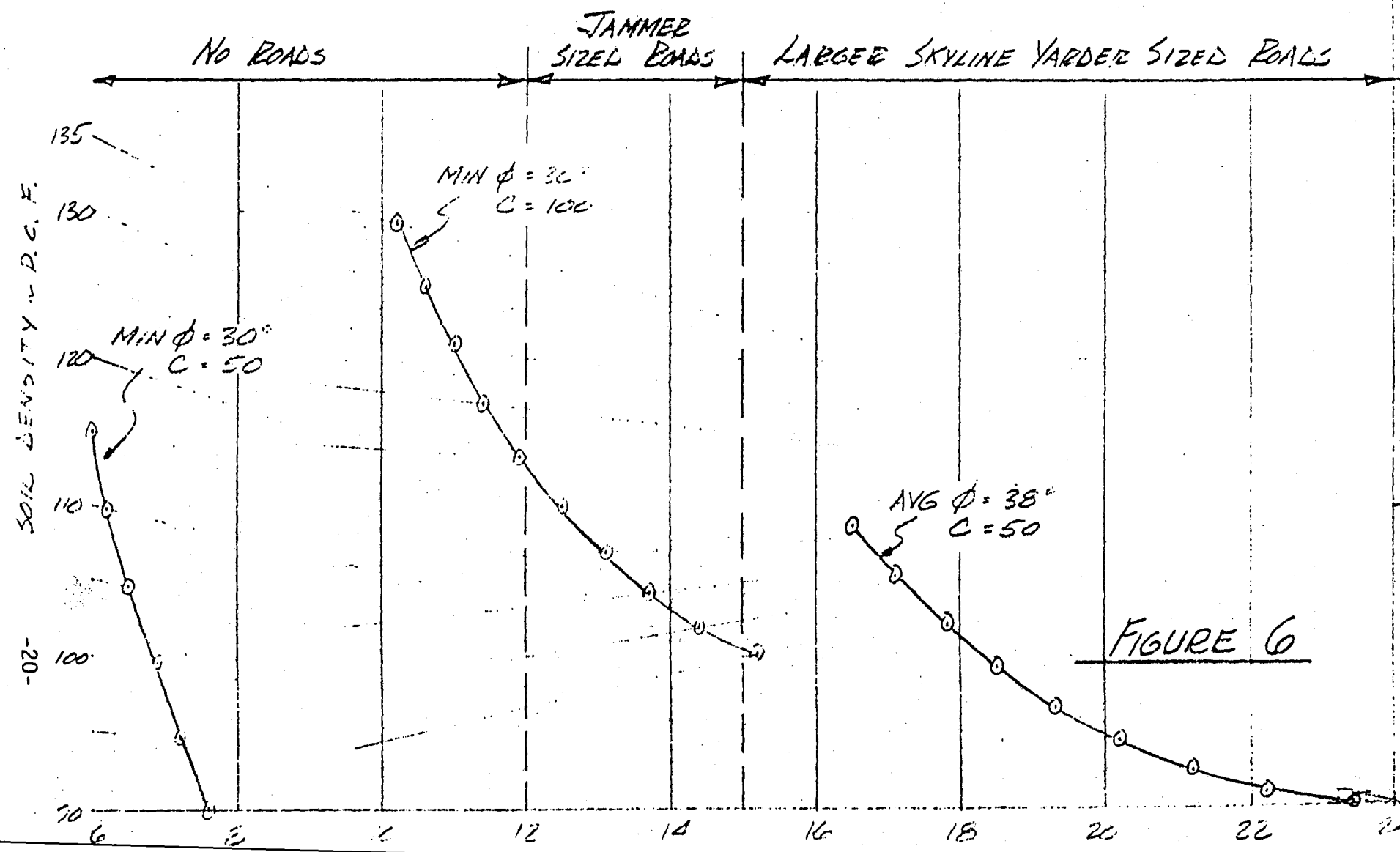


FIGURE 6

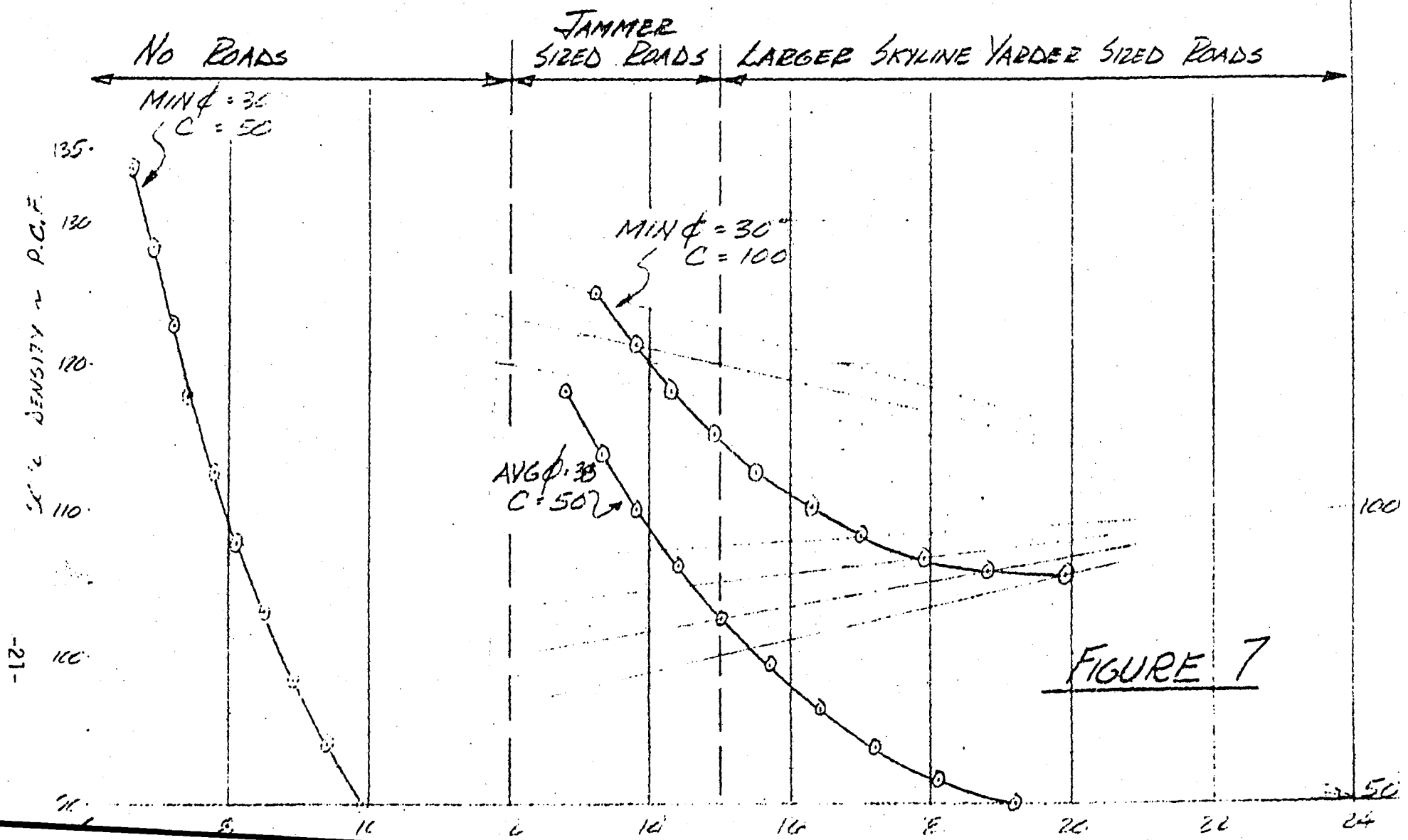

NO ROADS
JAMMER SIZED ROADS
LARGER SKYLINE YARDER SIZED ROADS
MIN ϕ = 30°
C = 50
MIN ϕ = 30°
C = 100
AVG ϕ = 35°
C = 50
135
130
120
110
100
100
50
8
10
12
14
16
18
20
22
24

FIGURE 7

SIDESLOPE — 60%
CUTSLOPE — 1:1
SOIL TYPE — 400 SERIES (PINE TY

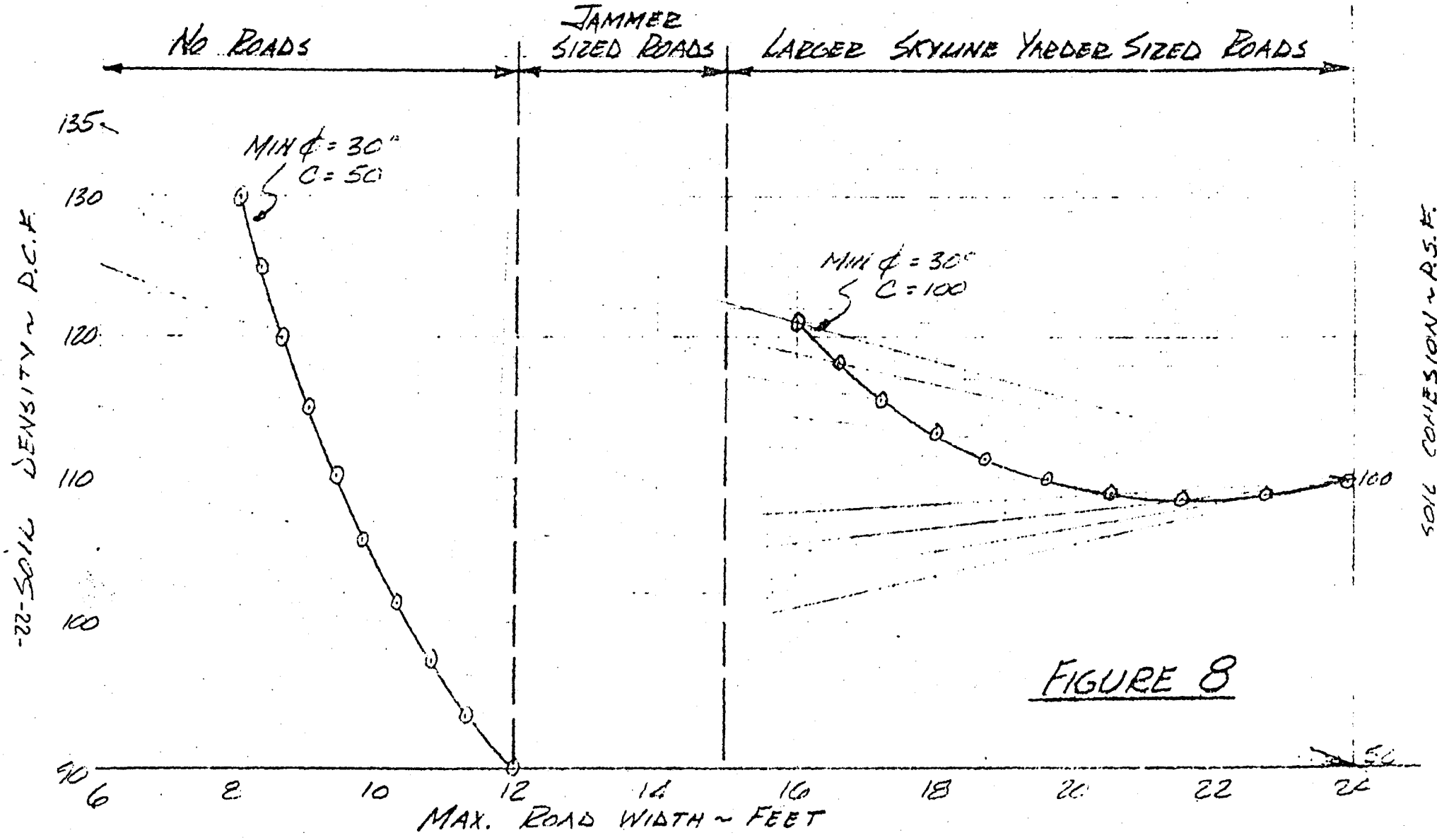


FIGURE 8

SIDESLOPE - 70%
CUTSLOPE - 3/4 : 1
SOIL TYPE - 500 SERIES (RESILIAL)
SOIL PARAMETERS - ϕ MINIMUM = 35°
ϕ MID-RANGE = 42.5°
ϕ MAXIMUM = 50°
COHESION @ 0-100 PSF
MIDRANGE @ 50 P.S.F.

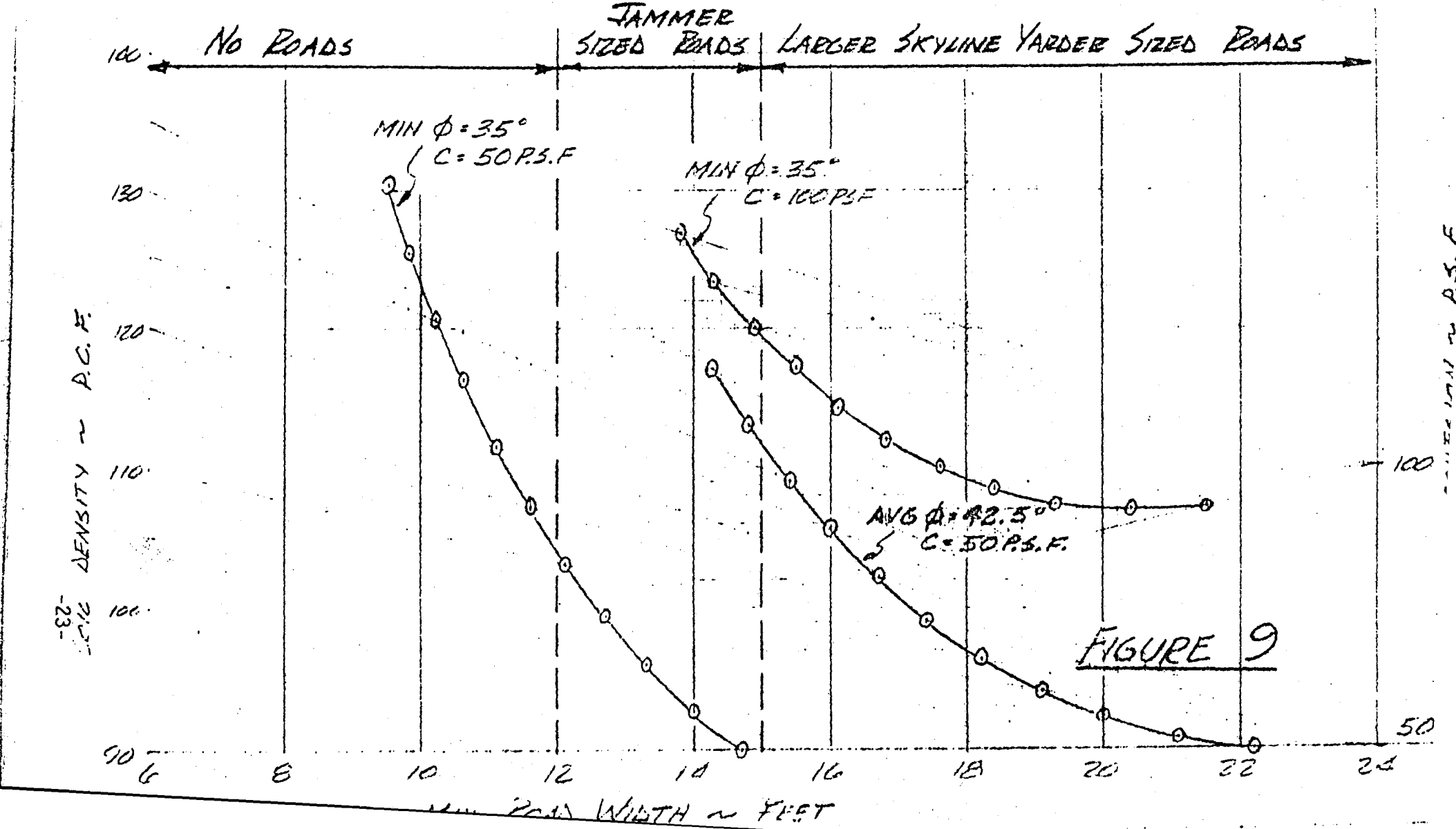


FIGURE 9

SIDESLOPES - 70%
CUT SLOPES - 1:1
SOIL TYPES - 500 SERIES (RESIDUAL)

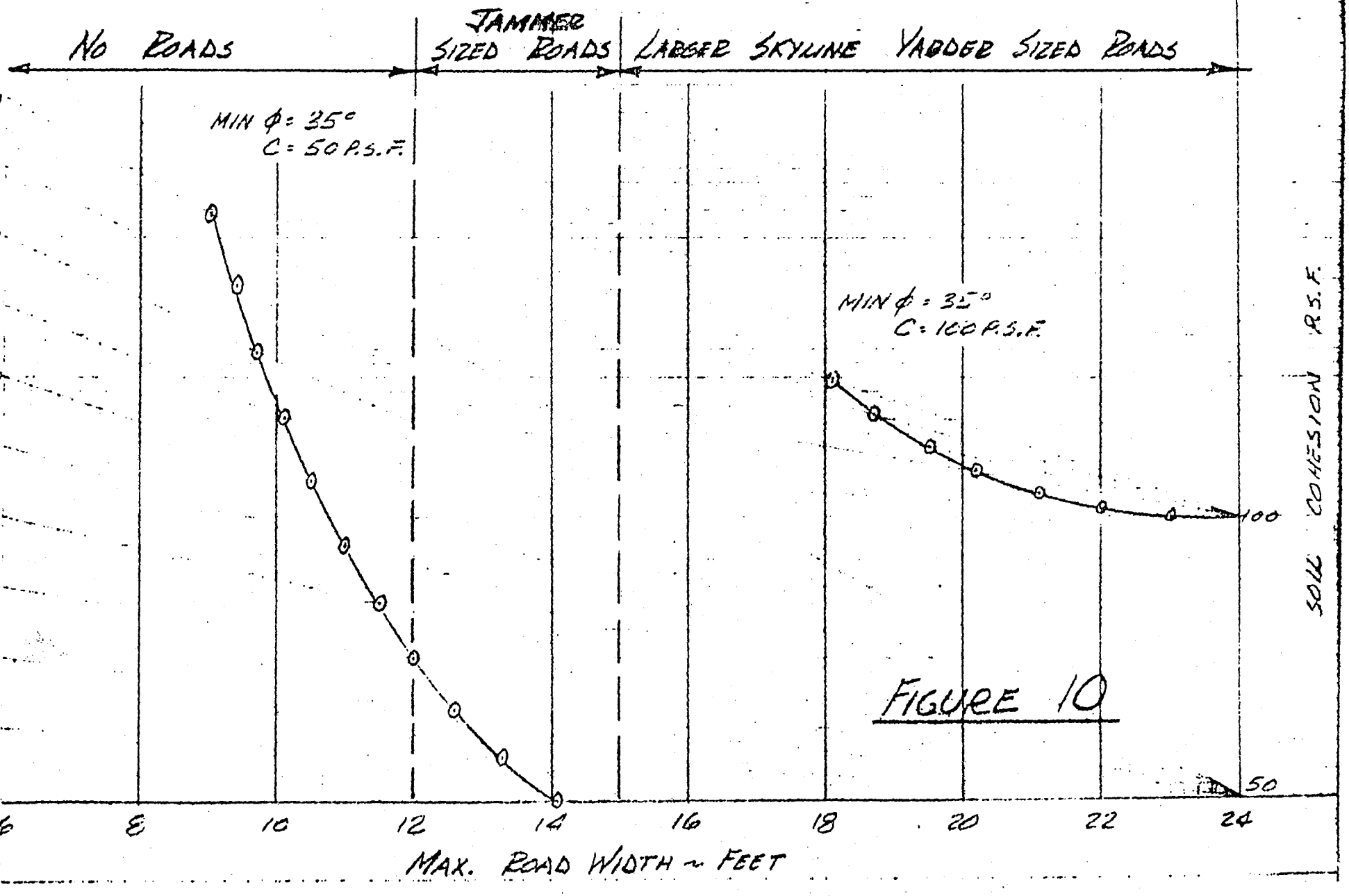


FIGURE 10

SIDESLOPES - 60%
CUT SLOPES - 3/4:1
SOIL TYPES - 500 SERIES (RESIDUAL)

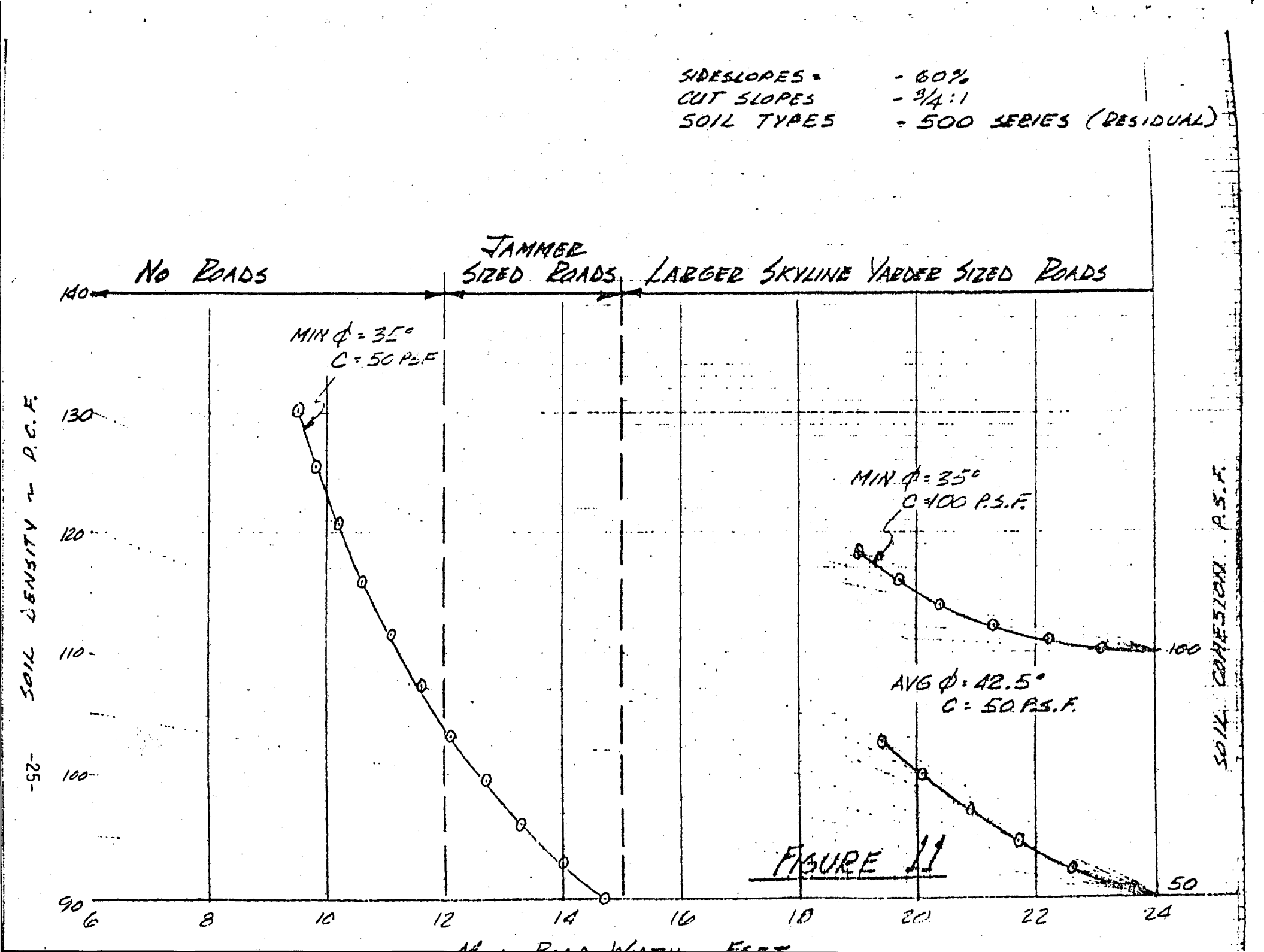


FIGURE 11

SIDESLOPE - 60%
CUTSLOPE - 1:1
SOIL TYPE - 500 SERIES (RESIDUAL)

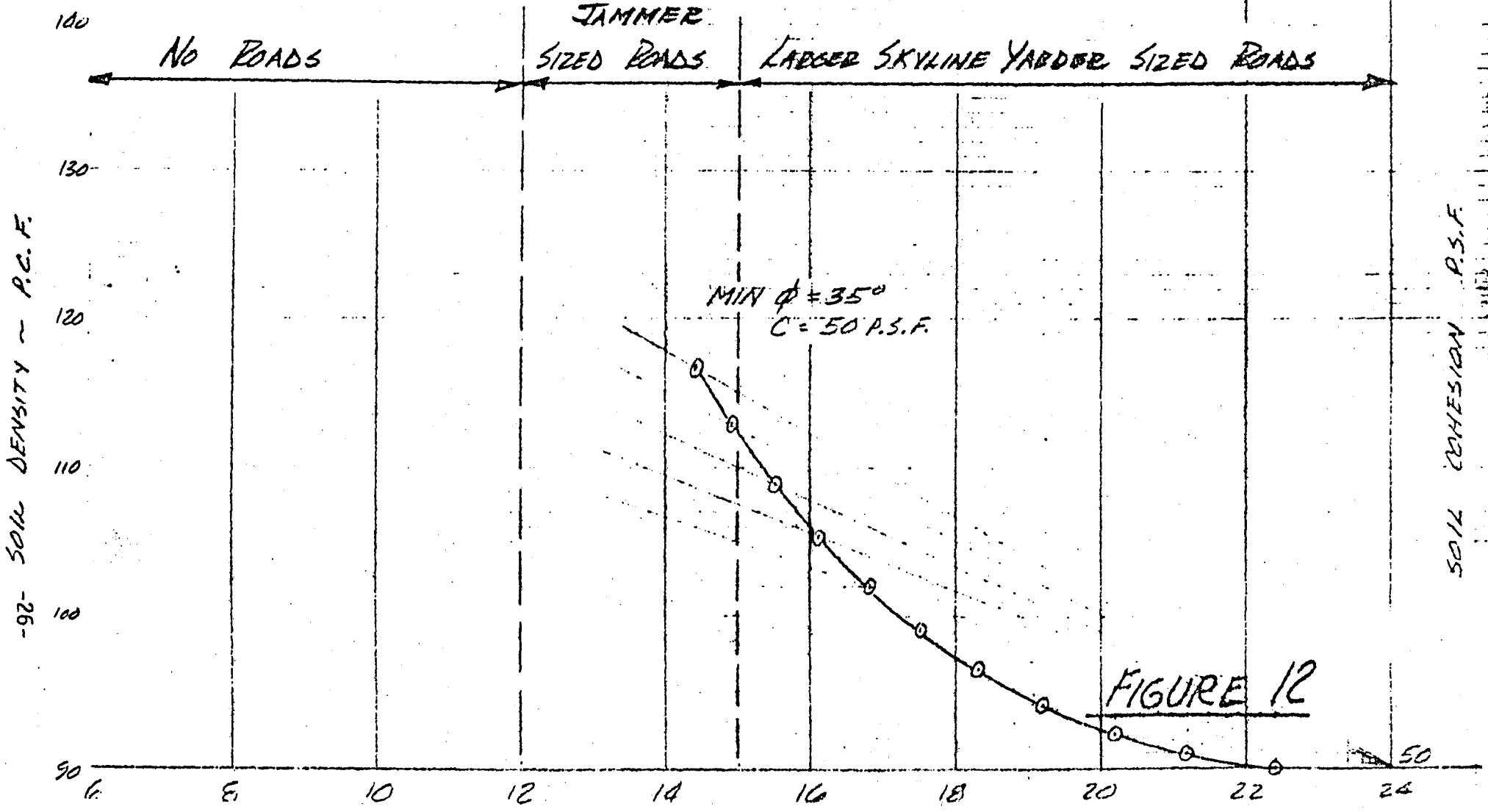


FIGURE 12

F. CONCLUSIONS

One obvious weakness of this approach is the broad range of stability observed even within a given land type. This range could be narrowed by evaluating a large number of tri-axial soil tests covering the area in question.

However, this testing is expensive and time-consuming. This doesn't mean its never justified. But by working with the soils specialists and materials engineer a more educated guess may be derived based on available evidence in the area. Thus, the wide range of possible widths can be narrowed to a more useful answer.

The hoped-for advantage of this approach is that it gives the planner some idea of the relationship between stability and road standards, slopes and land types.

The maximum road widths for Kootenai land types in various side slope and cut slope ratios using mid range ϕ, density and cohesion values are as follows:

Land type	60%		70%	
	3/4:1	1:1	3/4:1	1:1
200 series	23.0 ft.	24 ft. plus	16.0 ft.	20.0 ft.
300 series	21.4 ft.	24 ft. plus	15.6 ft.	19.5 ft.
400 series	15.4 ft.	24 ft. plus	11.3 ft.	19.8 ft.
500 series	21.4 ft.	24 ft. plus	15.7 ft.	24 ft. plus

It must be re-emphasized that over reliance on these widths as constituting reliable answers could be very dangerous. However, they provide an idea of what the overall situation on the Kootenai is regarding soil stability.

II - ROAD SPACING

A. INTRODUCTION

This section will relate primarily to the problem of determining the correct road spacing for skyline operations on steep (40% plus), straight and sustained slopes. Furthermore, it will provide a series of solutions that may be helpful in the preliminary planning of transportation systems.

A few individuals may still doubt there's any reason to consider skyline logging necessary on any land other than that classified in the marginal or special category. They may believe that conventional systems (tractors and jammers) are sufficient for timber harvest needs everywhere else.

However, several important points are overlooked by those subscribing to this over simplified approach. Specifically, there is a lot of terrain within the standard component that is too steep for tractor skidding. Most areas over 40% are in this category. On this steeper ground both jammers and skylines have the physical ability required for yarding. And each of these systems has its relative advantages and weaknesses. Jammer operations normally yard logs more economically, but with a less positive means of physically controlling the log. Consequently their use would often be specified in clear cuts. Skylines however, because of the better capacity to bring logs through a residual stand with a minimum of damage, should be specified normally in thinning and overstory removal operations. 1/ Therefore, it would be wise to lay out

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1/ This is not intended to infer that skyline operations should be overlooked in clear cuts. Where good deflection permits long spans a reduction in road costs and impacts can often be realized through skyline operations in clear cuts.

a road system from which either a skyline or jammer system can be used to provide 100% yarding coverage for the following reasons:

First, the cutting requirements on a timber stand change throughout the years, depending upon its stage of management and condition. For the most part we are now liquidating old growth with clear cuts. The subsequent stand will probably be managed more intensely, and therefore require several commercial thinnings. The Kootenai's future potential yield is in fact based on a Timber Resource allocation model that prescribes three commercial thinnings which will constitute a high percent of the total rotation's yield. While the reliability of this RAM program as to detailed accuracy may vary it seems an inescapable fact that thinning operations will play an increasingly important role in future timber management activities. Therefore, it would be advantageous to have roads that are now being constructed for access to clearcuts by jammers also be so positioned as to permit full skyline coverage for future thinning operations.

Some may doubt the necessity of this for the following reasons: We only consider the economic life of a road to be 20 years. As this year's clearcut stand won't be ready for commercial thinning for 50 years, we can re-develope the area as we need to when the time comes. Besides, who knows what new methods our technology may provide for logging at that point in time? Perhaps all yarding will be done with helicopters powered by atomic fusion?

There are some sound rebuttals however to these notions. The 20 year road life is based on what we find to be a convenient study period for benefit:cost type analysis. However, these roads, or the scars left by these roads, will not disappear that soon. At least at the price per mile it currently costs to construct them, we should hope they won't. No doubt some roads may be closed for periods of time and require sizeable reconstruction expenditures before resumed use is possible. Never-the-less, this would be definitely preferable to periodic abandonment and construction on a new location. Reconstruction of level roads that have been

originally built on the correct location should be a far more economical procedure than abandonment. Furthermore, minimization of the number of road scars placed upon the land exhibits a much better land management practice.

Logging systems of the future may indeed differ greatly from those of today. But the only system that offers hope for a basic revolution in timber yarding is now represented by the helicopter. As helicopters must expend large amounts of energy, their future role as the most economical and commonly used yarder seems far from assured.

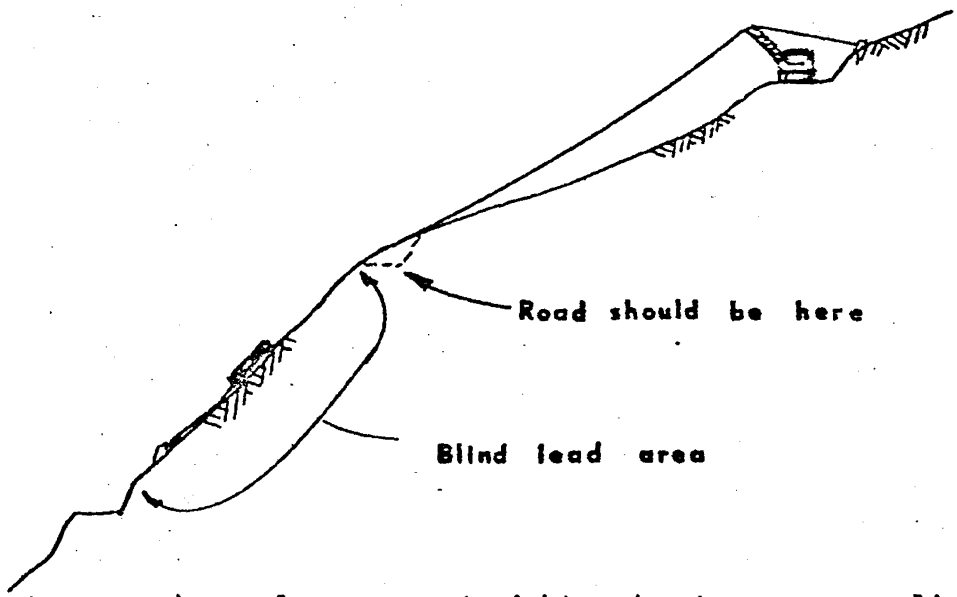
There are also many technical improvements foreseeable in skyline logging including: faster line speeds, stronger cable and smaller, more mobile yarders. However none of these, barring the invention of a cheap anti-gravitational force, will do much to change the basic need for a certain amount of deflection attainable from proper road placement. Greater cable strength will put higher demands on anchor trees or dead men anchors, so improvement in this avenue will be limited by soil strength. Even now anchor points are often the limiting factor in skyline operations.

Certainly we are given no guarantees on what the future may bring in the line of logging system capability. However, we ought to plan our transportation system with as much foresight and provide for as much flexibility as possible. We're "copping out" if we assume a technological miracle will occur in 20 years to rescue us from mistakes made now. Miracles can't be programmed.

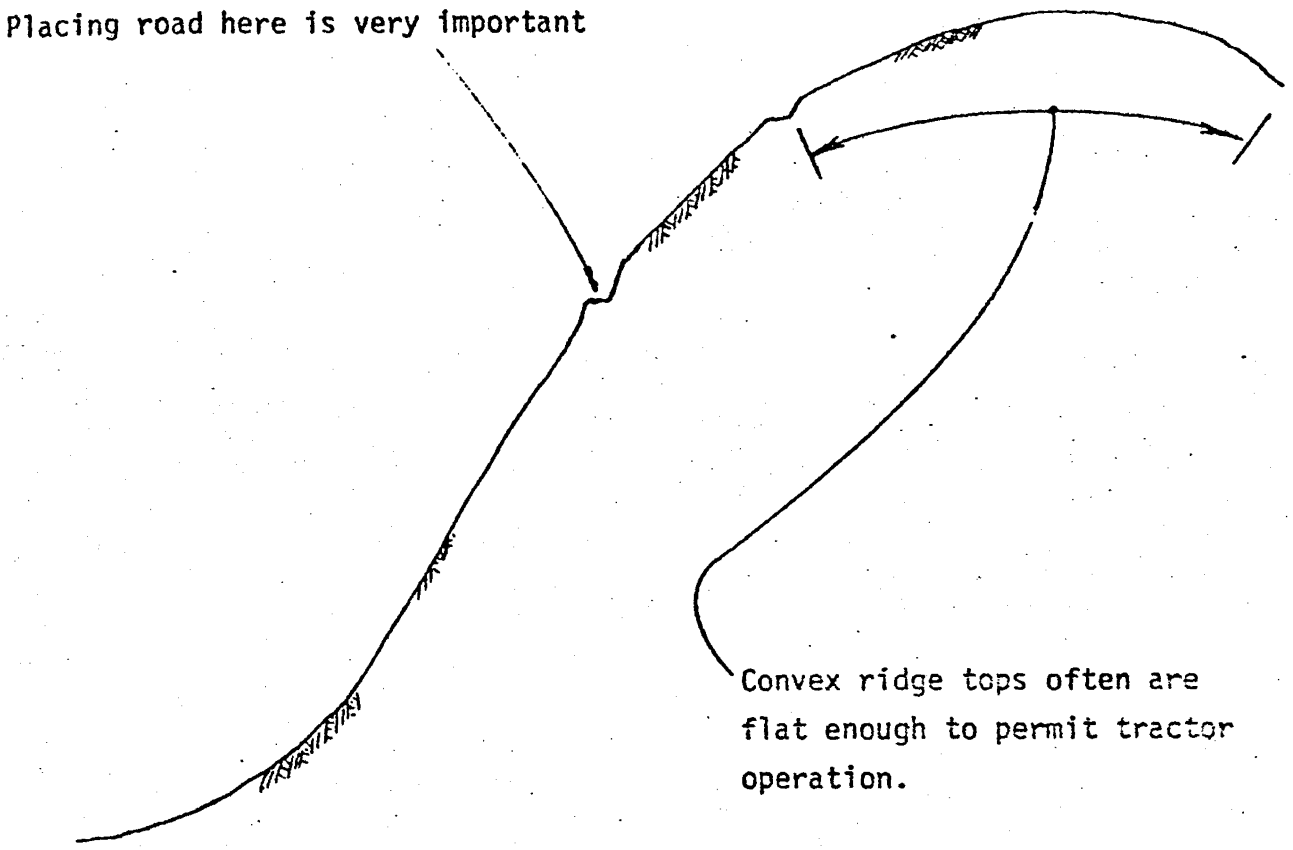
So the question is - how practical is it to lay out road systems that permit both jammer and skyline operability? The answer is - it is very practical and advantageous for the following reasons: The basic mobile skyline yarder has a maximum reach capability of 1000 feet. On the long straight slopes lacking in deflection that are quite typical of the Kootenai, it is more often than not, impossible to bring an adequate turn of logs in from 1000 feet. Also, there are large jammers available now that have 1000 feet

reach capability. Even the Skagit SJ-4 yarders used on the Kootenai operate in a jammer configuration and reach about 700 feet. While this is short of the maximum reach of many of today's skyline yarders it is fairly compatible with what the skyline yarder can attain under typical circumstances.

Jammer operations, especially at extreme yarding distances (over 500 feet) are hampered by poor deflection. While it may be possible to yard over a blind lead 600 feet out with a large jammer, it is not easy. To require it raises the logging costs and may create erodible trenches where the nose of the log plows through the top soil. Therefore, it would be advantageous to exercise care in placing level jammer roads to provide the best deflection possible and avoid the situation shown below:



In most cases where slopes are straight and not convex, realistic spans for a long span jammer and 1000 ft. skyline are quite compatible. Straight slopes are very characteristic of the Kootenai with some convexity near the top of the ridge and some concavity near the bottom. Often the convexity may be overcome if it is in the nature of the intersection of two straight slopes.



The following points need re-emphasis regarding the comparison between skyline and jammer operations. A skyline yarder cannot always operate over the terrain that an equal span jammer can cover. However, if greater care were taken in locating jammer roads it should generally permit skyline operation as well as facilitating the jammer operation.

The benefits of taking the extra time and care needed to properly place these roads consist of providing for an easier jammer operation and the possibility of skyline operability for future thinnings.

The costs of doing this are just the extra administrative time

and effort required to properly locate the new roads. Furthermore, this additional effort and expense is less than most realize. Once the procedure is established and practiced the truth of this statement becomes obvious. If jammer roads are spaced out on the basis of distance and without regard to deflection it is still necessary to slope chain the distance between adjacent mid slope roads to establish a few control points. The extra time required to take and record an abney shot is insignificant. Using a computer process for plotting these profiles, picking control points and checking deflections, speeds up the office portion of the analysis a great deal. Individuals on Districts that have developed a systematic method of using this procedure on skyline sales no longer dread the effort. On the contrary they seem to feel more secure with their road locations knowing a skilled layout has been completed. Furthermore, the high costs of today's road construction dictate that skill and care be used in our road layout work.

To provide further guidelines in this area a series of load tables are presented in this section. These show, under various described conditions, the largest turn of logs in weight, diameter and length that can be skyline yarded between adjacent roads. These tables are based on straight 40, 50, 60 and 70% slopes. The skyline payloads are listed for various elevation differences between roads ranging from 280 to 400 feet. Specific information concerning criteria will be explained in Section II-B of this report.

These tables are intended to give the transportation planner some "ball park" information for preliminary layout where straight slopes are prevelant. They are <u>not a substitute for the field profiles and analysis required</u> prior to the actual development of an area.

B. DATA BASIS FOR PAYLOAD TABLES

The skyline payload tables provided in this section are based upon the criteria illustrated on the following page.

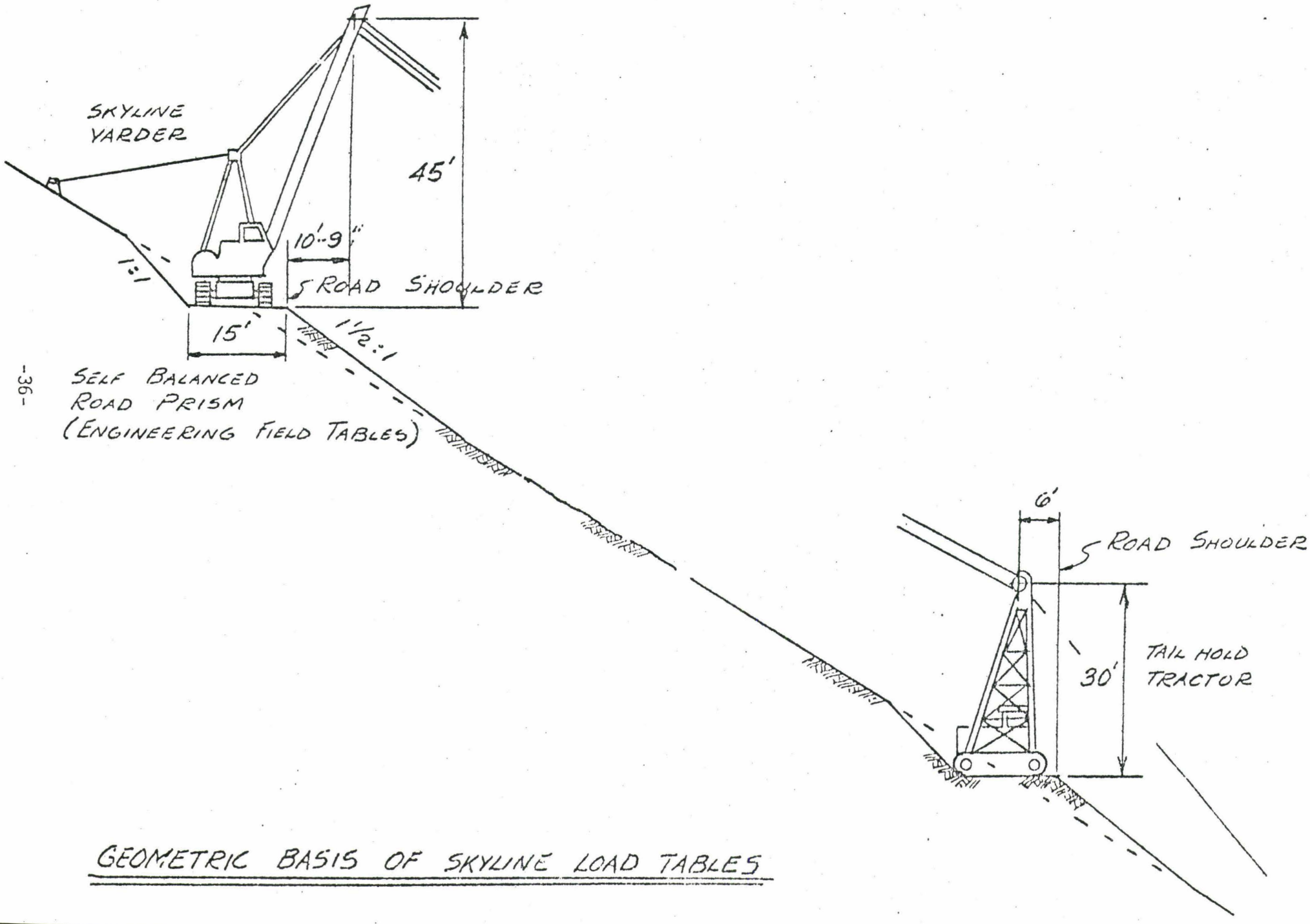
Additional criteria is as follows:

1. Running skyline system.
2. 3/4" haulback line w/ 17,100 lb. allowable tension.
3. 3/4" mainline (equivalent) w/ 17,100 lb. allowable tension.
4. 600 lb. slack pulling carriage.
5. 10 ft. minimum ground clearance for carriage.

The reasons for selecting this particular system and criteria are as follows:

(1) Running skyline operates better than most other single span skyline systems under limited deflection conditions.
(2 and 3) This is about as heavy a set of lines as we can expect to use with the type of running skyline yarders that operate in this area. Some have gone to lighter skylines (5/8") to reach longer spans where better deflection permits.
(4) This is about the lightest weight carriage (MAR 303) that provides slack pulling capability suitable for partial cut operations.
(5) 10 ft. clearance is about the minimum, and permissible only when short 8 ft. chokers are used. The logs will travel with only one end lifted and the tail end dragging under these circumstances. However, this is generally adequate for thinning operations.

The tower dimensions of the yarder shown on the following page conform to todays most commonly used running skyline yarders - the Skagit GT-3 and the Washington 78.



GEOMETRIC BASIS OF SKYLINE LOAD TABLES

The lift provided at the tail block tractor of 30 feet is in excess of the 25 ft. tower tractors presently used by St. Regis. However, 30 foot tower tractors are available and advantageous for longer reach.

In summary, the criteria were intended to provide the greatest possible distance between roads that can be realized with presently available equipment. There was no conservatism used in their application. Some skyline loggers claim you should have 10% deflection as a minimum for a good operation. However, this maxim developed in the coast Douglas-fir belt where larger logs are found, and would be overly conservative here.

The log sizes extrapolated from the payloads were based on a 40 pounds per cubic foot green log weight and an assumed taper of 1 inch per 8 foot of length. This should be fairly realistic for this area, as timber in this area runs lighter per unit volume than coastal timber.

As one end of the logs will drag on the ground in this minimum clearance situation it is assumed that 60% of the log weight will be supported by the skyline and 40% by the ground. The payload calculations were completed using the method outlined in PNW Research Paper-75 (Mechanics of Running Skylines).

Some of the payload tables (70% and 60%) are shown for only uphill yarding. That is that the entire area between adjacent roads will be yarded uphill with the yarder positioned on the upper road.

The 50% and 40% tables are shown for both modes of yarding. That is uphill only, and a combination of uphill and downhill yarding.

The reasoning for this is that there is a safety problem associated with straight downhill yarding on very steep ground. If there is an available bench enabling the yarder and crew to move away

from the toe of the steep slope it is a different story. Under those conditions downhill yarding should be utilized as a means of increasing road spacing. However, these tables are defined for straight slope conditions with a minimum width road. Therefore, straight downhill yarding was considered too hazardous on slopes over 50%.

SKYLINE PAYLOAD TABLES FOR STRAIGHT SLOPES
(UPHILL YARDING ONLY)

70% SIDESLOPE								60% SIDESLOPE							
ELEVATION DIFFERENCE BETWEEN ROADS (FEET)	Slope Distance Between Roads (ft.)	Gross Payload Capability (1000 lb. units)	Scaling diameter of maximum sized log or logs (inches)				% Deflection	Slope Distance Between Roads (ft.)	Gross Payload Capability (1000 lb. units)	Scaling diameter of maximum sized log or logs (inches)				% Deflection
			1-16' Log	1-32' Log	2-32' Logs	3-32' Logs				1-16' Log	1-32' Log	2-32' Logs	3-32' Logs	
280	488	6.43	51	35	24	19	7.85	544	6.23	50	34	24	19	7.11
300	523	5.99	49	34	23	19	7.27	583	5.83	48	33	23	18	6.62
320	558	5.59	47	32	22	18	6.77	622	5.42	47	32	22	17	6.19
340	593	5.33	46	31	22	17	6.32	661	5.10	45	30	21	17	5.82
360	628	4.88	44	30	20	16	5.93	700	4.79	43	29	20	16	5.48
380	663	4.58	42	29	20	16	5.58	739	4.47	42	28	19	15	5.19
400	698	4.30	41	27	19	15	5.27	777	4.21	40	27	19	15	4.92

SKYLINE PAYLOAD TABLES FOR STRAIGHT SLOPES
(UPHILL YARDING ONLY)

ELEVATION DIFFERENCE BETWEEN ROADS (FEET)	50% SIDESLOPE							40% SIDESLOPE						
	Slope Distance Between Roads (ft.)	Gross Payload Capability (1000 lb. units)	Scaling diameter of maximum sized log or logs (inches)				% Deflection	Slope Distance Between Roads (ft.)	Gross Payload Capability (1000 lb. units)	Scaling diameter of maximum sized log or logs (inches)				% Deflection
			1-16' Log	1-32' Log	2-32' Logs	3-32' Logs				1-16' Log	1-32' Log	2-32' Logs	3-32' Logs	
280	626	5.55	47	32	22	18	5.91	754	4.48	42	28	19	15	4.61
300	671	5.15	45	31	21	17	5.52	808	4.10	39	27	18	15	4.30
320	716	4.79	43	29	20	16	5.18	862	3.78	38	25	17	14	4.03
340	760	4.51	42	28	19	15	4.89	915	3.47	36	24	16	13	3.80
360	805	4.17	40	27	18	15	4.62	969	3.19	34	23	15	12	3.59
380	850	3.91	38	26	18	14	4.39	1023	2.83	31	21	14	11	3.31
400	894	3.66	37	25	17	13	4.18	1077	2.59	30	19	13	10	3.14

SKYLINE PAYLOAD TABLES FOR STRAIGHT SLOPES
(UPHILL & DOWNHILL YARDING COMBINED)

50% SIDESLOPE								40% SIDESLOPE							
ELEVATION DIFFERENCE BETWEEN ROADS (FEET)	Slope Distance Between Roads (ft.)	Gross Payload Capability (1000 lb. units)	Scaling diameter of maximum sized log or logs (inches)				% Deflection	Slope Distance Between Roads (ft.)	Gross Payload Capability (1000 lb. units)	Scaling diameter of maximum sized log or logs (inches)				% Deflection
			1-16' Log	1-32' Log	2-32' Logs	3-32' Logs				1-16' Log	1-32' Log	2-32' Logs	3-32' Logs	
280	626	9.11	60"+	43	30	24	10.18	754	7.72	57	39	27	22	7.75
300	671	8.61	60"+	41	29	23	9.48	808	7.22	55	37	26	21	7.21
320	716	8.13	60"+	41	28	22	8.85	862	6.75	53	36	25	20	6.73
340	760	7.69	57	39	27	22	8.33	915	6.38	51	35	24	19	6.34
360	805	7.33	55	38	26	21	7.87	969	6.00	49	34	23	19	5.97
380	850	6.93	54	37	25	20	7.43	1023	5.64	48	32	22	18	5.64
400	894	6.61	52	36	25	20	7.04	1077	5.35	46	31	22	17	5.37

C. RELATING SKYLINE LOAD TABLES TO THE LEVEL ROAD CONCEPT OF TRANSPORTATION PLANNING

The "level road" concept of transportation system layout has been commonly used on the Kootenai. In a nutshell, this concept determines the climbing roads that are required for the basic transportation system. Climbing roads furnish access to the level roads that are spaced to provide yarding access to the standard timber producing land. The number of climbing roads is restricted by land impact constraints, and to provide an economic balance between log haul costs and road construction costs. The required number of level roads is determined to provide an economic balance between yarding costs (which increase with greater road spacing) and area development costs (which decrease with greater road spacing). Also the number of level roads required may be controlled solely by the physical capability of the required yarding system. Where tractor skidding can be practiced the economic criteria can and should be applied to determine road spacing. However, where ground lead or skyline yarding is required the physical limitations of the yarding system generally govern and determine road spacing.

Typically a level road system that fully developes an area between two adjacent climbing roads covers a broad range of sideslopes as the terrain changes from relatively flat draws, to steep faces, to flatter ridges. The indicated yarding method also varies from tractors to ground lead or skyline. The transportation planner's task is to fit this unhomogenous maze into road system that as much as possible takes full advantage of the physical capability of the best yarding systems available, incorporates sound economic analysis, and minimizes the adverse environmental impact of road construction on the land. This would be difficult enough if the planner could isolate and analyze the road system on a piece by piece basis. The necessity of having to tie these pieces together

into a system by flat or reasonable grades limits his ability to achieve a road system that is ideal throughout. Trade offs are mandatory. The following simplified example is given to show how the skyline load tables may aid in evaluating trade offs in the transportation planning process.

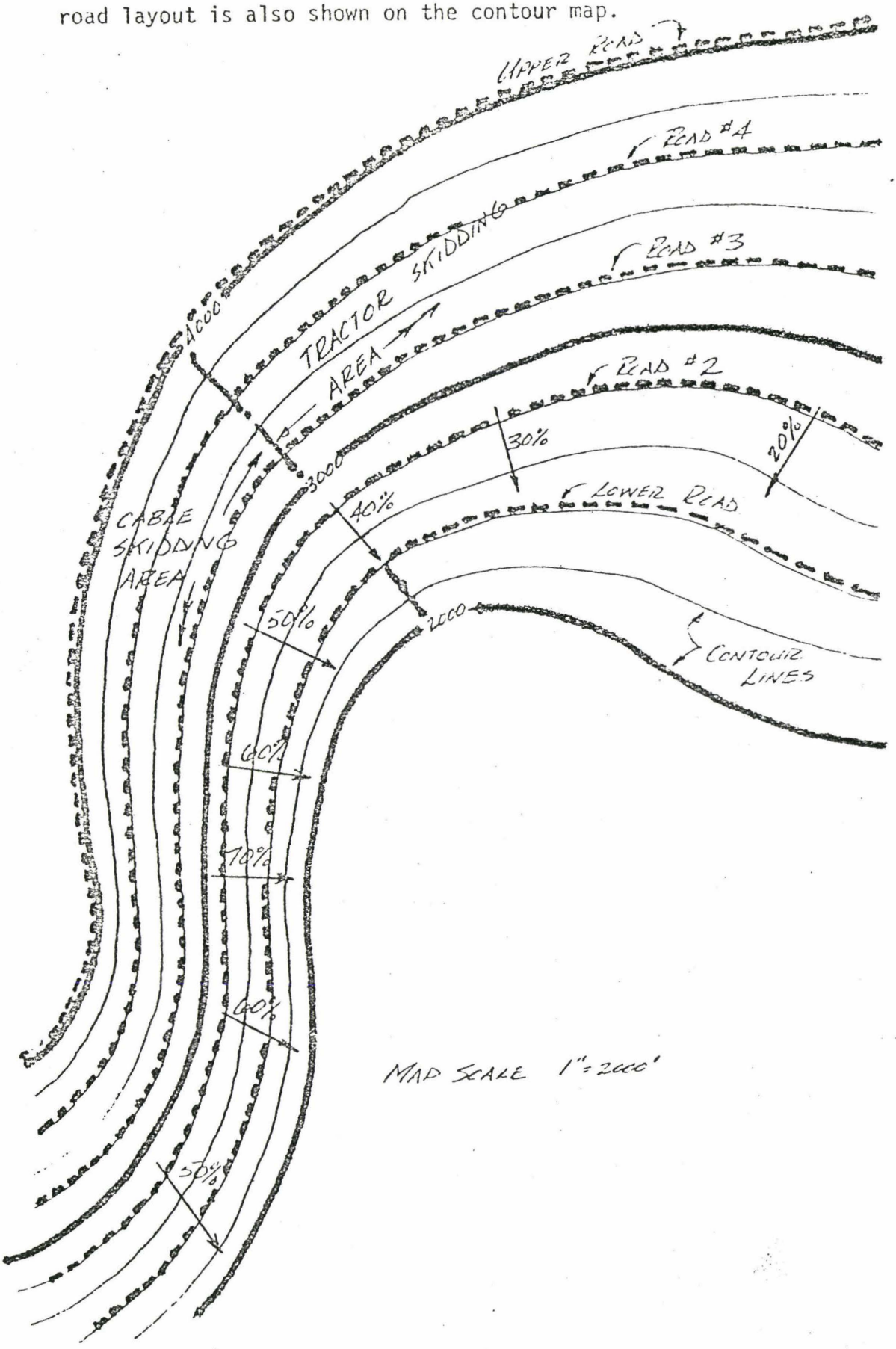
EXAMPLE 1

Assumptions:

1. Area is within the standard component of timber harvest.
2. Soils are stable.
3. Timber is overmature old growth.
4. Clearcutting is prescribed.
5. Topography is as shown on contour map on the following page.
6. Future management will require skyline thinning on steep terrain.
7. Assume 1000 ft. reach jammers and skylines are available.
8. Clear cut yarding will be done by the large jammers.
9. Skyline operability is needed for future thinning operations.

Examining the listed range of elevation differences between roads in the skyline payload tables (pages 39 - 41) it can be noted that payload capability diminishes as elevation difference increases. However, at 400 feet elevation difference there still should be adequate capability for a commercial thinning operation. If both uphill and downhill yarding is used on slopes less than 50%, a turn size of three 15" diam. x 32' logs can be yarded. A single 40" diam. x 16' log can also be handled. While this is not adequate capacity for skyline yarding in old growth it is decided between the forester and the engineer to be sufficient for skyline thinning. Furthermore, a large jammer should be capable of handling the existing old growth at this spacing by ground lead yarding. Therefore,

a tentative road spacing of 400 feet is selected. The resulting road layout is also shown on the contour map.



Now if silvicultural requirements or visual constraints eliminated clear cutting on this old growth stand a different approach is required. The reduced payload capacity associated with a 400 foot elevation difference in roads may not be adequate for skyline yarding old growth. A lesser elevation difference may have to be selected, depending upon the size of the timber, to assure reasonable operability.

The adequacy of the layout for tractor skidding on the flatter slopes must also be checked. The elevation differences listed in the skyline payload include slope distance between roads at various elevations. A projection of these slope distances to tractor ground shows the following:

Elevation Difference Between Roads (ft.)	Slope Distance Between Roads (ft.)		
	30% slope	20% slope	10% slope
280	974	1428	2814
300	1044	1530	3015
370	1114	1632	3216
340	1183	1734	3417
360	1253	1836	3618
380	1322	1938	3819
400	1392	2040	4020

If the desired elevation differences between roads on the high lead or skyline areas do not correspond reasonably well with optimum economic road spacing for tractor skidded areas adjustments should be made to attain better a cost balance.

Included in the appendix of this guideline is a paper that illustrates a method of solving for optimum or minimum cost road spacing for tractor skidded areas. This paper includes a table that gives the minimum cost spacing for a range of road costs and per acre volumes to be harvested based on listed assumptions. Checking this table shows that in this example the road spacings ranging from 1300 to 2000 feet on tractor ground may be reasonably close to minimum cost road spacing limits, depending upon the road cost

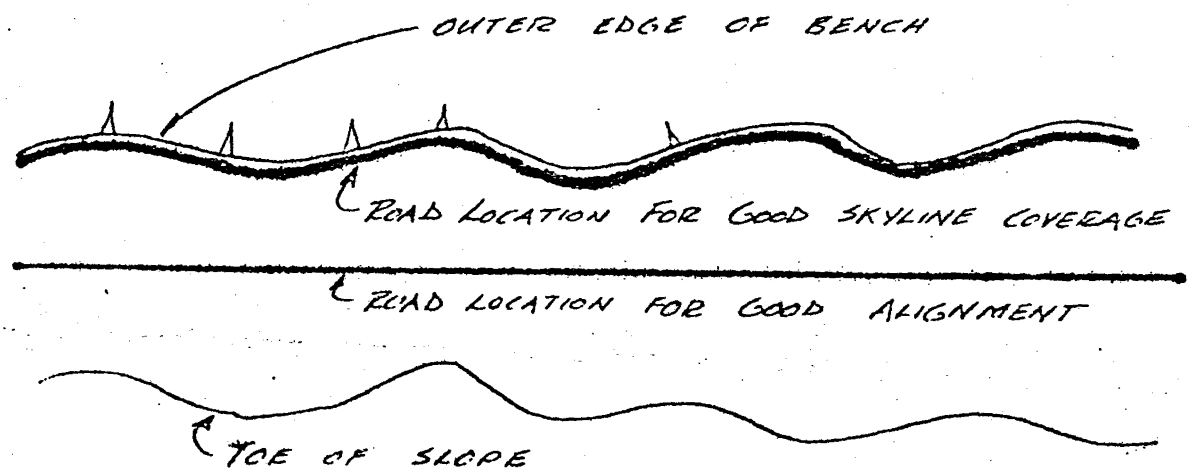
per mile and cut volume per acre. Again it must be emphasized, trade offs are inevitable. If the road spacing on tractor ground is inadequate it can be adjusted by climbing spurs. Analysis and judgement are required.

In conclusion it must be stressed that these skyline loadpath tables are for preliminary study and layout. Also they should assist in determining what size payloads are required. Though the straight slope analogy often approximates the slopes found here it is wrong to assume straight slopes in actual road layout. Slight benches and slope changes can drastically affect the skyline operability on slopes appearing to be basically straight. These benches can greatly increase or reduce skyline reach, depending upon how the roads are placed with respect to the topography. Field measured slope profiles are required prior to the actual flagging of roads.

overrule the use of advantageous pitches of grade.

Often road locations can be moved off steep slopes to benches by using pitches of grade. These grade adjustments can be used to reduce total excavation and/or to facilitate skyline coverage of an area. Generally the ideal road location for skyline coverage is at the outer edge of benches, while the location that provides the best alignment and least excavation is more often in the center of a bench.

As the usual reason for the roads' existance is timber harvest the alignment considerations must be sacrificed if they interfere with the roads primary function.



D. RECOMMENDED VARIATIONS OF THE LEVEL ROAD CONCEPT OF TRANSPORTATION PLANNING

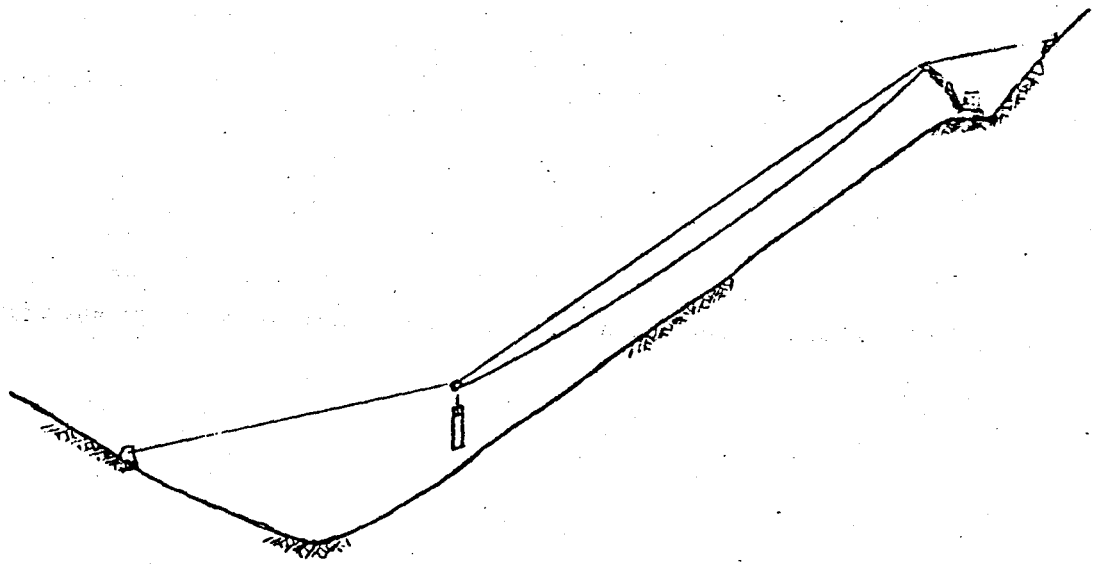
There are many instances when the constraint of constructing strictly flat (0% grade) roads may prevent the planner from attaining an efficient road system. However, the level road concept does not rule out grade pitches in level roads. Some misunderstanding may have occurred on this point. Words have a tendency to confuse at times. Level should mean level, but this is not always the intent. At least not where a more efficient system with less total impact can be achieved by climbing or dropping "level" roads.

The ability of an outsloped level road to drain water without a ditch is a primary advantage where it is desirable to restrict road width without diminishing running surface. A 12 foot running surface is generally the minimum requirement for a single lane road, and without a ditch the basic road prism need not exceed 12 feet. However, where skyline yarders or larger jammers are used for yarding a 12 foot road width is inadequate. Roads about 15 foot wide are generally required for this longer span equipment. As the trend seems to be swinging toward use of this longer span equipment most new areas developed with level roads should provide for this road width. Now a 12 foot road with a standard ditch section provides basically a 16 foot road prism, which is adequate for this type of yarder. The yarder must encroach on the ditch when set for operation, but this presents no problem that ditch reshaping with a grader won't solve. On this basis there's little to be gained by avoiding a ditch, at least where road width is concerned. The difference in road prism width between a 15' road without a ditch and a 12' road with a ditch is only one foot. Admittedly the outsloped road has the additional advantages of not collecting run-off or requiring as many culverts. But in total none of the advantages of an outsloped road are sufficiently significant to

E. CLIMBING ROAD CONCEPT OF TRANSPORTATION PLANNING

Under some circumstances it may be advantageous to use concepts other than the level road plan in laying out transportation systems. Such a concept is presented here; and for lack of better name it can be called the climbing road plan.

A primary advantage of using this concept can occur in drainages where the creek climbs at a reasonably mild grade, but the side slopes of the drainage are quite steep. If it is desirable 1/ to minimize the amount of road construction in this area by use of skyline yarders this approach is often useful. The primary strategy behind this type of layout rests with achieving good deflection for the maximum skyline reach from the first road above the creek for uphill yarding. There are relatively small mobile yarders available (Madill 071 and others) capable of 2000 ft. skyline spans. These can be used to maximum advantage under these circumstances.



1/ It is usually desirable from an environmental standpoint of course to minimize the amount of road construction. Economic analysis may show that this savings in road cost is more than lost by causing higher yarding and haul costs. If so it must be decided whether the environmental benefits exceed the operating loss. Or the economic analysis may show the savings in road costs exceed the increase in yarding costs. In this case both environmental and economic considerations may point to the same course of action.

This full span capability can only be maintained if the road maintains its position relative to creek bottom. As the creek drops the road must also drop in order to maintain this position of roughly 1500 feet of slope distance above the creek. The remaining roads required above the first road should remain at the elevation difference required for the deflection allowed from the first road.

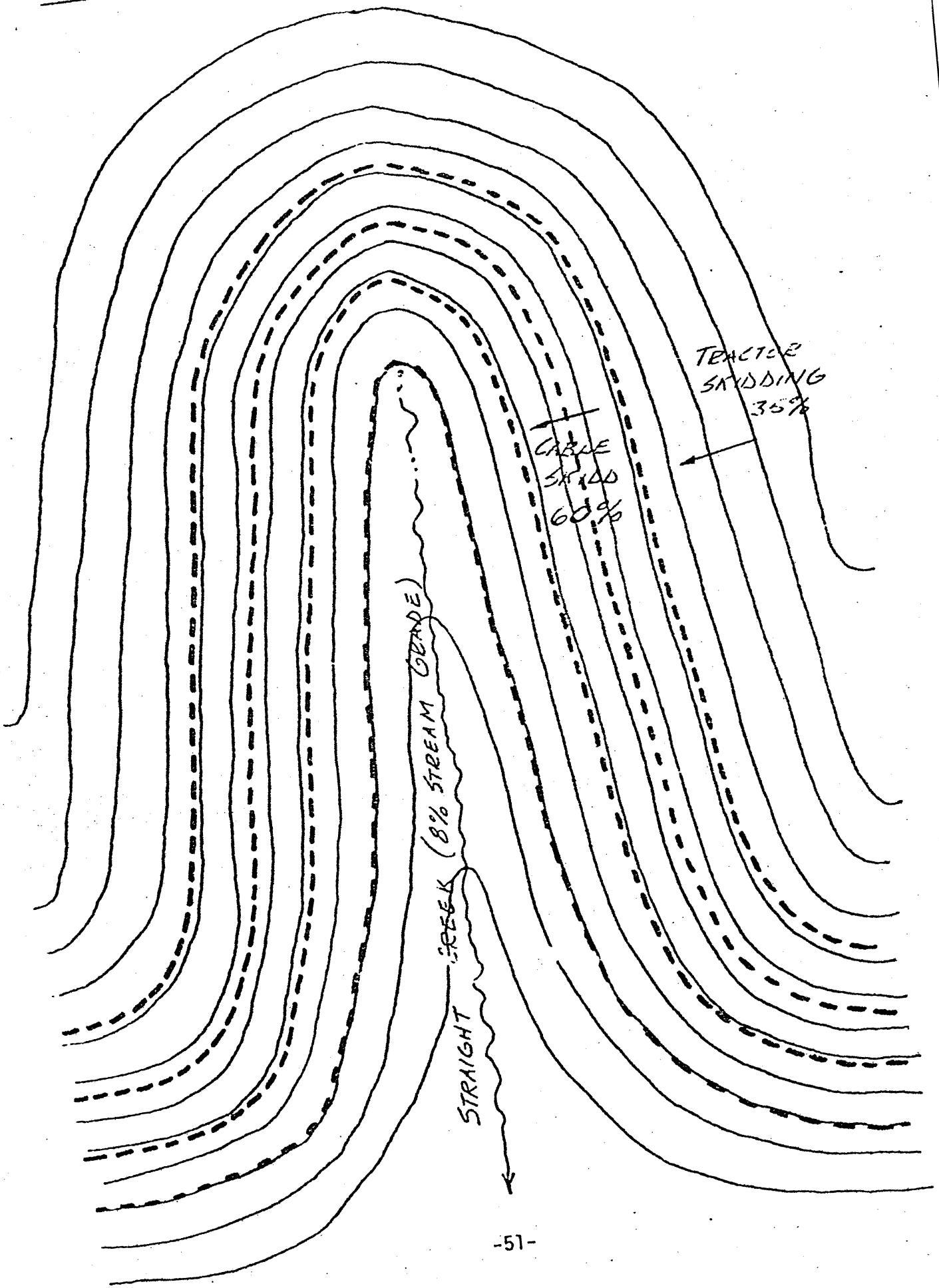
The level road concept will permit a full 1500 foot skyline for only a short portion of the road's length, and then loose the advantage of utilizing the yarder's full span capacity as the creek climbs closer to the level road.

An example layout comparing the two (level vs. climbing) systems is shown on the following pages. Full yarding coverage of the contoured area by the level road system was provided assuming the use of large jammers or 1000 ft. skyline systems. The steep ground was basically 60% sideslope, and a slope distance between roads of 700 feet was assumed because the straight slope condition prevailed. The total length of level roads in this layout was measured at 15.4 miles. The climbing road plan was laid out under the same assumptions with the exception of the first road which was placed at 1500 feet slope distance above the creek. Here the road length was 11.4 miles. The climbing road plan provided yarding coverage of the drainage with 4.0 miles less road than the level road plan in this drainage. The roads required are somewhat longer than the level roads, as they go further up the drainage, but fewer roads are required.

Generally to take full advantage of skyline span capability a layout concept similar to the climbing road plan is required more often than not. Level roads may in places (reaching across a creek) provide opportunities for long spans. However, as the road system continues around the ridge the straight slope condition prevails and road spacing is limited to what can be skylined under this more limiting condition.

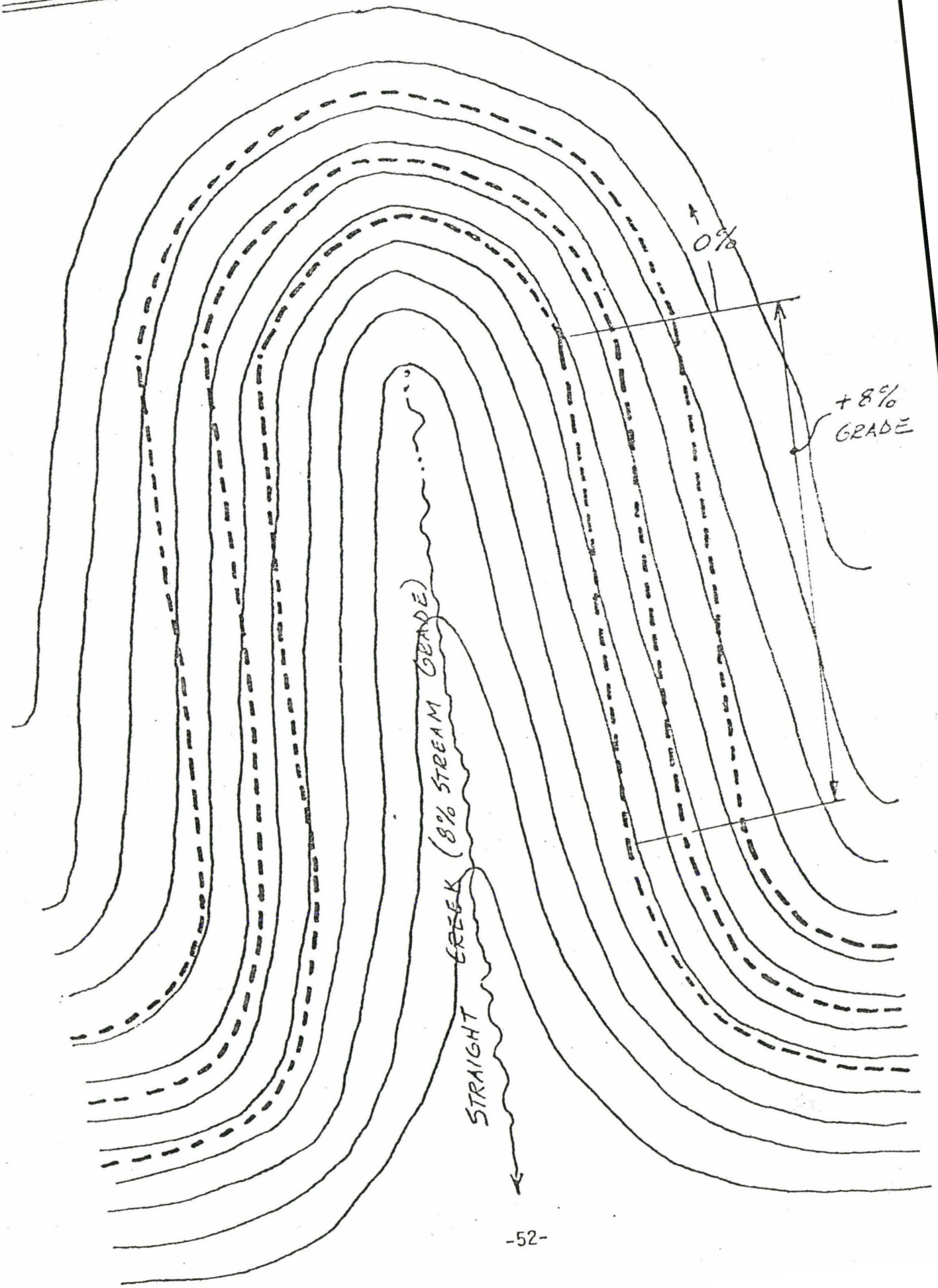
LEVEL ROAD PLAN

SCALE: 4" = 1 MI.
200' CONTOUR INTERVAL



CLIMBING ROAD PLAN

SCALE: 1" = [illegible]
200' CONTOUR INTERVAL



III - ROAD LOCATION PROCEDURE

A. ESTABLISHING GROUND CONTROL

This section outlines briefly a recommended method of establishing the ground control points required prior to location of roads. The procedure requires running field profiles. While the steps recommended are perhaps quite obvious it may never-the-less be helpful to review and document them. As mentioned in the preceeding section, this process should be followed for most roads where cable (jammer or skyline) logging is planned.

The preliminary (office) steps are:

1. Draw the required profiles on 4" per mile (or larger scale) contour map.
   a. Use straight edge.
   b. Run profiles generally straight up the slope. (This may not be possible throughout the length of the profile. They may have to be askew to portions of the slope, but should be perpendicular to the contours for as much of the profile as possible).
   c. Choose the correct number of profiles. (This depends upon the uniformity of the terrain. Where the terrain is variable it may be necessary to space profiles 300 feet apart. In more uniform terrain 600 to 1000 feet may be adequate. Good judgement is required).
   d. Determine the required length of the profiles. (They should be sufficiently long to encompass the area planned now for development, but not any longer).
   e. Key profiles to points which can be identified in the field. (Use existing roads, creeks or other positive land marks).
   f. Number the profiles on the map.
   g. Remember to profile areas where roads will be built outside

of the planned cutting units as well as those inside these units. (The new road construction must serve these tributary areas in the future as well as the areas presently planned for harvest).

h. Determine the correct compass bearing of each profile and record it on the map.

The field procedure steps are as follow:

1. Basic surveying tools should include an abney level, compass, 100 ft. tape, flagging, and metal numbered tree tags or similar permanent markers with aluminum nails.
2. A two man crew works best.
3. Start the profile at the recognizable landmark mentioned under point e above.
4. Head chainman reads the compass bearing mentioned under point h above. (He is responsible for keeping the profile running on a straight and predetermined course).
5. Rear chainman reads abney shots to the chaining points and keeps notes.
6. Profile line should be flagged every 100 ft.
7. A small piece of flagging placed on the ground by the head chainman every 100 feet (or major break) is sufficiently accurate to mark the chaining point.
8. The numbered metal tags should be nailed into trees at the beginning and end of each profile, and at selected intervals along the profile. (Generally use these tags about every 200 feet along the profile, at least when near to expected road locations).
9. Record the relative or differential elevation on each profile. (If profiles intersect an existing road it may be possible to record altimeter readings along the road to determine these profile elevation differences).

The field notes should include the following information:

Point	Slope Dist. in feet	% Abney	Remarks
			Date: 6/15/75
			Crew: Laurel & Hardy
			Profile #6 - Brg. S43W
1.			Ditch Line of Existing Road
	15	0	
2.			Shoulder of Existing Road
	25	-65	(Elev. 4060 based on altimeter reading)
#1042TT			Metal Tag in 16" doug fir near toe of road fill
	100	-48	
3.			Good anchor trees here. (P. Pine
	100	-46	18-30" dbh.)
4.	etc.	etc.	

While this basic profiling procedure may seem a burdensome addition to the work load, experience has shown that it's not that time consuming. Once the procedure is established it goes quite rapidly. Some Districts have divided 4 men road survey crews into 2 smaller crews, each of which can run two or three fairly long (1500 ft. plus) profiles per day. Such a 4 man crew on the Cabinet District ran about 23 profiles which adequately covered a sale requiring 5 MMbf of skyline logging in 5 working days. Compared with the other field work necessary to get a sale of this size prepared this is probably a modest addition. Furthermore, it is a well justified addition. Insuring that the sizable investment in road construction we make adequately accomplishes its intended purpose is a matter of the utmost importance.

B. UTILIZING THE GROUND CONTROL POINTS

The utilization or span design process requiring the information obtained by field profiles involves quite a detailed procedure. A full explanation will not be offered here. However, in general it involves the following steps:

1. Plot the ground profile to scale on cross section paper.
2. Label the points on the profile where the numbered metal tags were placed.
3. Determine tentative road locations on the profile where the skyline yarder and tower will be positioned.
4. Pick tail hold locations along the slope that will provide for full yarding coverage of the area.
5. Run the skyline load path analysis for this proposed span.
6. If adequate clearance for the desired skyline payload is not available make the necessary adjustments.
7. Arrive at a final road placement design for each profile.
8. Check to see if the roads on adjacent profiles can be connected by flat or reasonable grades.
9. If roads cannot be connected by reasonable grades make further adjustments until a road system that provides skyline coverage is designed.

This design work should be done by an individual who has had specialized training in skyline logging systems. Those familiar with the basic "chain and board" skyline analysis can complete a satisfactory analysis and layout. A quicker method of analyzing and solving this layout is through use of the desk-top computer and plotter available at the Supervisor's Office.

Once the correct positioning of the road system has been completed on the profiles the layout man knows where the roads should be located with respect to the metal tree tags in the field. Often

the roads will not fall exactly by a numbered tag. It may be necessary to measure upslope or downslope along the profile some distance and mark these control points. The road location can then commence, with care being taken to hit the established control points.

Even with this process being carefully done there still exists the possibility that blind leads, or small areas that cannot be covered by skyline yarding can occur. Essentially the profiles represent a systematic sampling of the topography of an area. It is assumed that if the road system is adequate at the profiles it will also be adequate between the profiles. However, this may not always be true. In any random sampling procedure there always exists the possibility of error, unless a 100% sample is taken. But 100% sampling (a profile every 50 feet) is too expensive a procedure. Therefore, the practical compromise appears to be taking an adequate number of profiles, and hoping for the best. Generally, if the profiles locations are picked with good judgement, and adequate road layout providing full skyline coverage results. Part of this good judgement entails picking the poorest deflection chances to profile.

APPENDIX

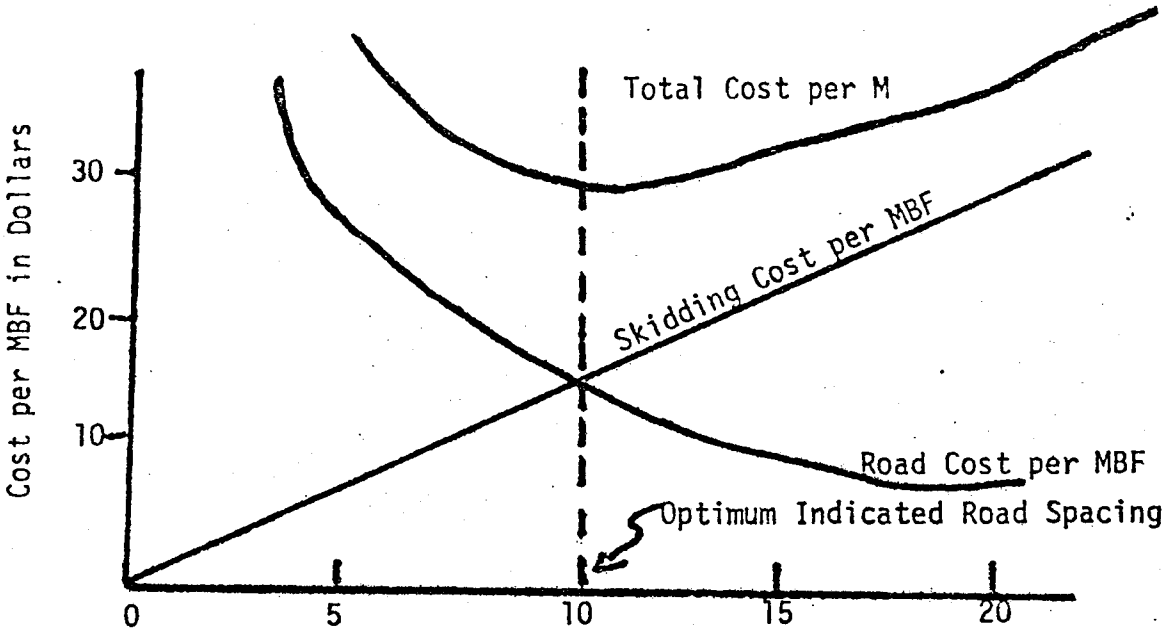
I. INTRODUCTION

This paper outlines a technique for determining the road spacing of level, timber harvest roads planned for areas and timber sales where tractor and jammer skidding is predominant. A mathematical "model" is constructed and average conditions and data for the Kootenai National Forest are utilized. The results from the model are tabulated, showing the minimum cost solution, or the road spacing that results in the lowest total road construction plus skidding cost in timber harvest areas.

The results indicated here indicate we could in some cases be planning our road system at a greater spacing than we would normally use. This is based only on what the logger's costs actually are. If we could assign real costs to environmental considerations and weighed them accordingly, a further increasing of road spacing would be indicated. For these roads do constitute the major impact on the land resulting from logging. However, this model utilizes only logging cost, which are more clearly defined and predictable than sedimentation damage, etc.

II. MATHEMATICAL MODEL

This model is based on the premise that road spacing affects skidding costs, i.e. the greater the road spacing, the greater the skidding cost and the less the road construction cost will be. Finding the optimum combination results in the minimum total cost as illustrated in the following chart:



The Timber Management H.B. (2423.51-1) illustrates the method used in appraising skidding for Forest Sales. The main variables affecting skidding are: (1) volume/acre cut, (2) log size, (3) slope distance skidded, and (4) scaling defect. This paper utilizes that approach. To simplify the compilations, two of the variables (log size and defect) are held constant, while the approach could be expanded to show a variance of all variables, it does represent a considerable amount of calculation time. Kootenai National Forest averages from 12 random timber sales indicate log sizes to be as follows: Lodgepole pine-26 logs/M, larch-14 logs/M, spruce-15 logs/M, hemlock-grand fir-20 logs/M, Douglas-fir-16 logs/M, white pine-16 logs/M, cedar-17 logs/M, and ponderosa pine-7 logs/M. An over-all average of 16 logs/M was used in the following calculations. The scaling defect was held at 12 per cent.

The following example is provided to illustrate how the minimum cost spacing is determined:

A. Skidding Cost

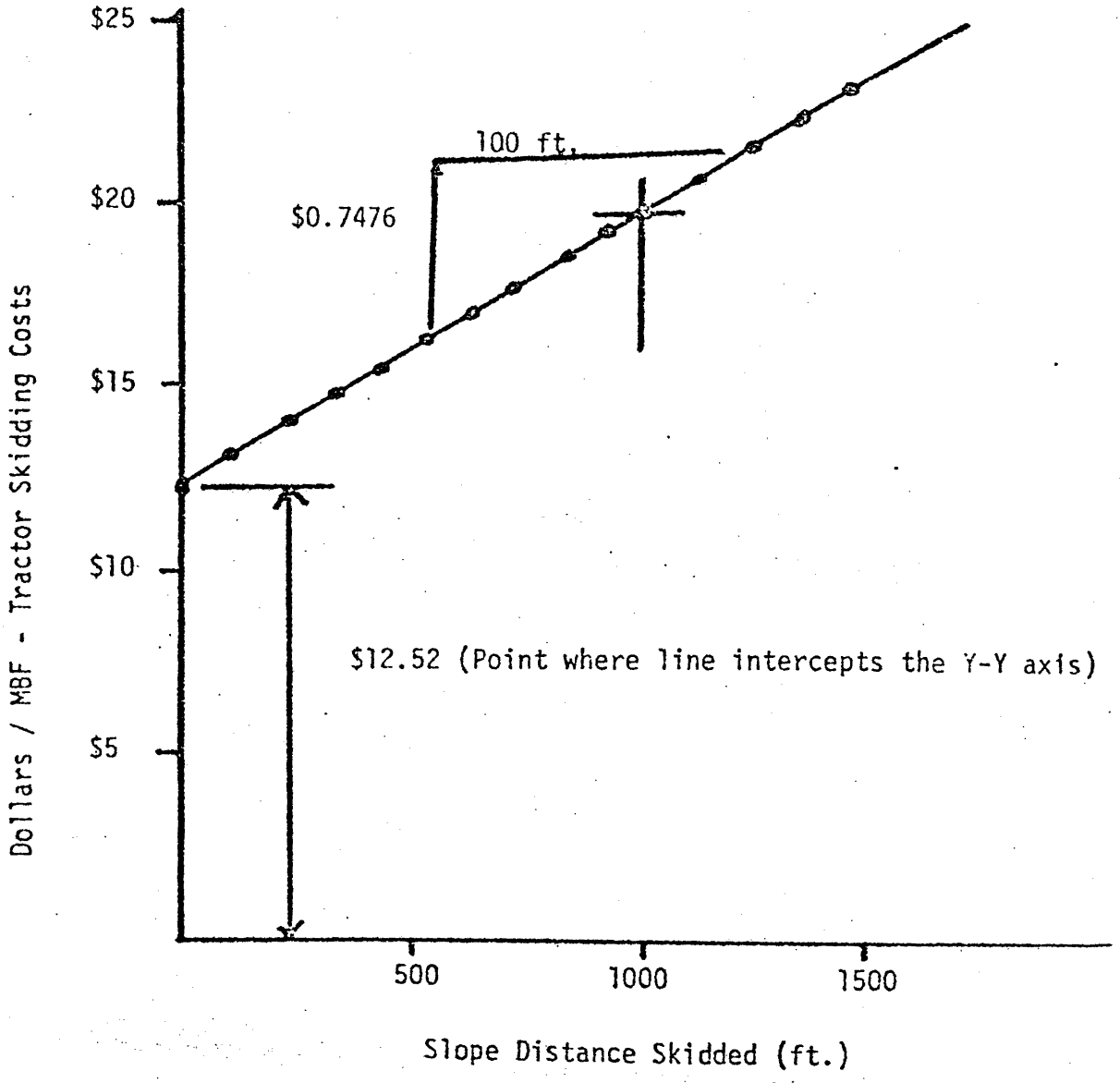
The volume cut per acre in this example is assumed at 16 MBF per acre. Therefore, the adjustment percentages (see T MHB 2423.51-3 - July 1974) are as follows:

Total Adjustment Excluding Slope Distance

volume/acre (16MBF) = -1
log size (16 logs/M)= 0
scaling defect (12%)= +6
+5%

Base Rate	Slope Dist. Adjustment	Remaining Adjustment	Net Adjustment	Adjusted Cost
$15.98	100' = -22	+5	-17 or .83	$13.26
$15.98	200' = -17	+5	-12 or .88	$14.06
$15.98	300' = -13	+5	- 8 or .92	$14.70
$15.98	400' = - 8	+5	- 3 or .97	$15.50
$15.98	500' = - 3	+5	+ 2 or 1.02	$16.30
$15.98	600' = + 1	+5	+ 6 or 1.06	$16.94
$15.98	700' = + 6	+5	+11 or 1.11	$17.74
$15.98	800' = +11	+5	+16 or 1.16	$18.54
$15.98	900' = +16	+5	+21 or 1.21	$19.34
$15.98	1000' = +20	+5	+25 or 1.25	$19.98
$15.98	1100' = +25	+5	+30 or 1.30	$20.77
$15.98	1200' = +30	+5	+35 or 1.35	$21.57
$15.98	1300' = +34	+5	+39 or 1.39	$22.21
$15.98	1400' = +39	+5	+44 or 1.44	$23.01
$15.98	1500' = +43	+5	+48 or 1.48	$23.65

These costs plotted over the range of slope distances are illustrated in figure 1.



Equal to 2/3 of external (or maximum) yarding distance.

FIGURE 1. Tractor skidding costs where the following conditions exist:

volume cut/acre = 16MBF
logs/MBF = 16
scaling defect = 12%

The plotted skidding costs illustrated in Figure 1 can be fitted reasonably well with a straight line. In simpler terms, the skidding cost is directly, or linearly, related to skidding distance. This

straight line can be conveniently expressed by the following equation (1):

(1) $C = 12.52 + 0.7476\ d$

where

C = Skidding cost in $/MBF

d = Slope distance skidded in 100 ft. stations.

Now "d" is defined in TMHB (2423.51-1) as being equal to 2/3 of the external or maximum yarding distance. It is a fair assumption to equate the maximum yarding distance to the distance between truck roads, and assume no uphill skidding. Justification of this assumption is provided in the appendix of this paper. Therefore equation (1) is modified as follows:

(2) $C = 12.52 + 0.7476\ (2/3\ s)$

or

$C = 12.52 + 0.4984\ s$

where

s = spacing between truck roads. (in 100 ft. stations)

B. Road Costs

Road Construction costs include initial survey, design, staking and construction costs plus some allowance for minimum road maintenance such as cleaning culverts, removing debris, etc., for the economic period considered.

This example assumes a road construction cost of $14,000/mile. This cost represents a fair average cost for the Kootenai National Forest, since complete disposal of slash plus timber purchaser construction and design have become standard expenditures.

Assuming a unit area 1.0 mile long by 4,000 feet wide (size unit selected actually makes no difference in the outcome of this analysis)

results in the following road construction requirements and costs:

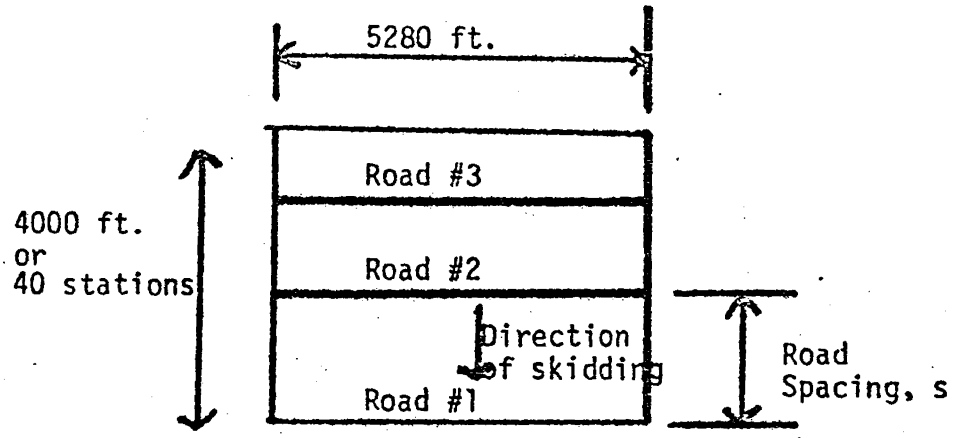


FIGURE 2.

(3) $R.C. = \frac{40}{s}$ ($14,000)

or

(3) R.C. = 560,000 s -1

where

R.C. = Total Road Cost

s = Road Spacing in 100' stations

C. Interest and Discounting Considerations on Costs

All costs considered will not occur at the same time. For instance all the land area between the constructed roads will not be clearcut at the same time the roads are constructed. Management constraints relating to the size of clearcut units have been imposed because of hydrologic, aesthetic and restocking considerations. As some of the timber skidding costs will be deferred to a later time, the costs should be discounted to their present value. The assumption made for this example is that 1/3 of the volume will be cut initially

(at the same time the roads are constructed), 1/3 of the volume will be cut 15 years hence, and the remaining volume will be cut in 30 years. The interest rate assumed is 6%.

Therefore, the composite discount factor for the skidding costs can be calculated as follows:

(% Total Volume) x (Present Worth Factor)

or

(.333) (1.000 - initially) = 0.3333
(.333) (0.4173 - 15 years) = 0.1391
(.333) (0.1741 - 30 years) = 0.0580

Composite discount factor = 0.5304

Annual road maintenance costs must likewise be discounted to their present worth. This example assumes $50/mi/year, and can be assumed for the full 30 year period. Actually the diminished importance of discounted costs beyond the 30 year period makes their consideration more academic than practical. The present value of these future annual maintenance costs is as follows:

(Present worth of 30 yr. cost annuity) x (Annual maintenance cost)

or

(13.7648) ($50.00) = $688.24

This cost can be added to the per mile construction cost of the roads, and equation (3) is modified as follows:

$$(4) \quad R.C. = \frac{40}{s} \quad (14{,}000 + 688.24)$$

or

$$(4) \quad R.C. = 587{,}530\ s\ -1$$

where

R.C. = Total Road Cost

s = Road Spacing in 100 ft. stations

D. Total Logging Costs*

These can be expressed as the sum of the Road Costs and Skidding Costs as follows:

*It is recognized that this is not total logging costs, but only the portion of the logging costs that is most affected by road spacing.

Total Cost = Discounted Road Cost + Discounted Skidding Cost

and

Total Discounted Road Cost = 587,530 s -1

whereas

Discounted Unit Skidding Costs = (12.52 + 0.4984 s) 0.5304

Discounted Unit Skidding Costs = (6.641 + 0.2644 s)

However, the total volume skidded in this area must be calculated.

Area in acres = (5280) (4000) ÷ 43,560

Area in acres = 484.85 acres

Volume skidded = (484.85 acres) (16 MBF/acre

Volume skidded = 7,758 MBF

Therefore, the total skidding cost is the cost per MBF x Volume in MBF or expressed as follows:

S.C. = (6.641 + 0.2644 s) 7,758

S.C. = 51,518 + 2,051.10 s

Now the total road plus skid costs can be expressed as follows:

T.C. = 587,530 s -1 + 51,518 + 2,051.1 s

The optimum road spacing, "s" that results in the minimum total logging cost can be readily determined by applying minimization

(or maximization) techniques of calculus. In short, the expression is differentiated with respect to "s", and the new expression is equated to zero. Solving the new expression yields a value of "s" that minimizes the total cost, T.C. This is done as follows:

$$dTC/ds = -587,530\ s^{-2} + 2051.1 = 0$$

or

$$2051.1 = \frac{587,530}{s^2}$$

$$s^2 = \frac{587,530}{2051.1}$$

$$s = \sqrt{286.45}$$

$$s = 16.95 \text{ stations}$$

Therefore, the solution that provides the minimum total road construction plus skidding cost in this example is a road spacing of 16.95 stations (or 1695 feet) slope distance.

III. CONCLUSIONS

Once this method is established it is fairly easy to work a reasonable number of variables, and determine the corresponding most efficient road spacings. This is done and a table illustrating the results is included at the end of this section, showing harvest volumes ranging from 12 to 28 MBF/acre, and road construction costs ranging from $6,000 to $20,000/mile. In addition, a second table is provided which shows the most economical road spacing if all the timber between the constructed level roads is cut at the time the roads are constructed. Naturally the road spacings shown on the second table are considerably less than indicated in the first case where some harvest is deferred.

Current average road costs have recently increased, and are approximately $14,000/mile. This example indicates an optimum road spacing of 1695 feet. We have in the past generally used a 1000 foot spacing

for transportation planning on tractor skidding type terrain. Using the wider spacing could often mean that two level roads would suffice where three roads had previously been indicated. Looking beyond the harvest of old growth timber to the commercial thinning operations anticipated on this terrain further complicates the situation. However, current practice is to thin flatter terrain with small skidding tractors. Therefore, there appears no compelling reason to vary from the optimum indicated spacing.

TABLE I

Minimum Cost Road Spacing 1/ in Feet of Slope Distance
Where Tributary Timber is Harvested over a 30 year period

Road Cost $/Mile	Volume/acre to be Harvested				
	12 MBF	16 MBF	20 MBF	24 MBF	28 MBF
6000	1319	1142	1022	933	863
8000	1503	1302	1164	1063	984
10000	1667	1444	1291	1179	1091
12000	1817	1573	1407	1284	1189
14000	1954	1693	1514	1382	1280
16000	2083	1804	1614	1473	1364
18000	2205	1909	1708	1559	1443
20000	2320	2009	1797	1640	1519

1/ Assumptions the above table is based upon are as follows:

1. Skidding costs are based upon the variation with distance as provided in 2423.51-1 (July '74) of TMHB.

2. Average defect is 12%.

3. 16 logs/MBF.

4. One third of area will be harvested initially, one third in 15 years, and remainder in 30 years.

5. 6% interest rate is assumed.

6. Distance between roads is assumed to equal the external yarding distance.

TABLE II

Minimum Cost Road Spacing 1/ in Feet of Slope Distance

Where All Tributary Timber is Harvested Immediately

Road Cost	Volume Area to be Harvested				
$/Mile	12 MBF	16 MBF	20 MBF	24 MBF	28 MBF
6000	961	832	744	679	629
8000	1095	948	848	774	717
10000	1214	1052	941	859	795
12000	1323	1146	1025	935	866
14000	1423	1233	1103	1007	932
16000	1517	1314	1175	1073	993
18000	1606	1390	1244	1135	1051
20000	1689	1463	1309	1195	1106

1/ Assumptions the above table is based upon are as follows:

1. Skidding costs are based upon the variation with distance as provided in 2423.51-1 (July '74) of TMHB.

2. Average defect is 12%.

3. 16 logs/MBF.

4. All the area will be harvested immediately upon completion of the roads.

5. 6% interest rate is assumed.

6. Distance between roads is assumed to equal the external yarding distance.